



***White Sands Missile Range 2007 Urban Study (W07US):***  
**Data Analysis, Volume DA-1**  
**(Analysis of Disaster Response Drills**  
**and Concurrent Atmospheric Data)**

by Gail Vaucher

---

ARL-TR-5706

October 2011

## **NOTICES**

### **Disclaimers**

The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

# **Army Research Laboratory**

White Sands Missile Range, NM 88002-5501

---

**ARL-TR-5706****October 2011**

---

***White Sands Missile Range 2007 Urban Study (W07US):***  
**Data Analysis, Volume DA-1**  
**(Analysis of Disaster Response Drills**  
**and Concurrent Atmospheric Data)**

**Gail Vaucher**  
**Computational and Information Sciences Directorate, ARL**

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188		
<p>Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing the burden, to Department of Defense, Washington Headquarters Services, Directorate for Information Operations and Reports (0704-0188), 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to any penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.</p> <p><b>PLEASE DO NOT RETURN YOUR FORM TO THE ABOVE ADDRESS.</b></p>					
1. REPORT DATE (DD-MM-YYYY) October 2011		2. REPORT TYPE Final		3. DATES COVERED (From - To) 2007 March–April	
4. TITLE AND SUBTITLE <i>White Sands Missile Range 2007 Urban Study (W07US): Data Analysis, Volume DA-1 (Analysis of Disaster Response Drills and Concurrent Atmospheric Data)</i>			5a. CONTRACT NUMBER		
			5b. GRANT NUMBER		
			5c. PROGRAM ELEMENT NUMBER		
6. AUTHOR(S) Gail Vaucher			5d. PROJECT NUMBER		
			5e. TASK NUMBER		
			5f. WORK UNIT NUMBER		
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Computational and Information Sciences Directorate Battlefield Environment Division (ATTN: RDRL-CIE-D) White Sands Missile Range, NM 88002-5501			8. PERFORMING ORGANIZATION REPORT NUMBER ARL-TR-5706		
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)			10. SPONSOR/MONITOR'S ACRONYM(S)		
			11. SPONSOR/MONITOR'S REPORT NUMBER(S)		
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT <p>This research is intended to calibrate the effectiveness of the 2007 Army Research Laboratory (ARL) safety procedures, by analyzing coincident atmospheric measurements sampled during three disaster response drills. In 2007, ARL conducted an urban field study called <i>White Sands Missile Range 2007 Urban Study</i> or <i>W07US</i>, which characterized the airflow and stability around an urban building. Three disaster response drills were executed concurrently with the atmospheric data acquisition. These drills included Simulated Fire, Bomb and Airborne Chemical Release threats. This report describes the atmospheric measurements acquired during the <i>W07US</i> field study drills, the human response for each drill and evaluates the effectiveness of the safety procedures executed, with respect to the concurrent atmospheric conditions. The multiple observations are reduced to practical –lessons learned.” A post-script section highlights some of the subsequent safety procedure changes and technology developments that have resulted from this investigation.</p>					
15. SUBJECT TERMS atmospheric urban studies, disaster response drills, simulated fire, bomb, and airborne chemical release threat, urban models					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			Gail Vaucher
Unclassified	Unclassified	Unclassified	UU	128	19b. TELEPHONE NUMBER (Include area code) (575) 678-3237

Standard Form 298 (Rev. 8/98)  
Prescribed by ANSI Std. Z39.18

---

## Contents

---

<b>List of Figures</b>	<b>vi</b>
<b>List of Tables</b>	<b>x</b>
<b>Acknowledgments</b>	<b>xi</b>
<b>Executive Summary</b>	<b>xiii</b>
<b>1. Research Objective</b>	<b>1</b>
<b>2. Background</b>	<b>1</b>
2.1 <i>WSMR 2007 Urban Study (W07US)</i> Field Study and Disaster Response Drills.....	2
2.2 <i>W07US</i> Field Test Site .....	3
2.3 <i>W07US</i> Atmospheric Data.....	3
2.3.1 Data Locations.....	4
2.3.2 Data Types.....	4
2.3.3 Data Time Series .....	6
2.3.4 Data Analysis Resources .....	7
<b>3. Fire Drill and Smoke Release</b>	<b>8</b>
3.1 Fire Drill Activities .....	8
3.2 General Atmospheric Conditions on the Fire Drill Day.....	9
3.3 Measured Atmospheric Data during the Fire Drill.....	12
3.4 Safety Drill Observations .....	12
3.4.1 Was the Rally Point Safe? .....	12
3.4.2 Was the Search/Rescue Re-entry Point Safe? .....	13
3.4.3 Mandatory versus Training Rally Points.....	13
3.4.4 What if the Drill had Occurred during the Prevailing Westerly Winds? .....	13
<b>4. Simulated Bomb Threat</b>	<b>15</b>
4.1 Simulated Bomb Threat Drill Activities .....	15
4.2 General Atmospheric Conditions on the Simulated Bomb Threat Day .....	16
4.3 Measured Atmospheric Data during the Simulated Bomb Threat Drill.....	19

4.4	Safety Drill Observations .....	22
<b>5.</b>	<b>Simulated Airborne Chemical Release Drill</b>	<b>22</b>
5.1	Simulated Airborne Chemical Release Drill Activities .....	22
5.2	General Atmospheric Conditions on the Simulated Airborne Chemical Release Drill Day .....	23
5.3	Measured Atmospheric Data during the Simulated Airborne Chemical Release Drill.	25
5.4	Model Simulations .....	28
5.5	Safety Drill Observations .....	29
<b>6.</b>	<b>Assimilating Drill Observations</b>	<b>31</b>
<b>7.</b>	<b>A Valuable Lesson Learned</b>	<b>31</b>
<b>8.</b>	<b>Summary</b>	<b>32</b>
<b>9.</b>	<b>L-REAC™ System, an Implemented Recommendation</b>	<b>35</b>
<b>10.</b>	<b>Mission Accomplished</b>	<b>36</b>
<b>11.</b>	<b>References</b>	<b>37</b>
	<b>Appendix A. Smoke Release Drill Summary</b>	<b>39</b>
	<b>Appendix B. W07US Thermodynamic Data, 2007 March 28–April 2 (JD# 87-92)</b>	<b>41</b>
B-1	SW Tower.....	42
B-2	Roof Tripod .....	46
B-3	NE Tower .....	49
B-4	South Tower .....	53
B-5	North Tower .....	57
	<b>Appendix C. W07US Dynamic Data (Sonic) by Disaster Response Drill Day (2007 March 29, March 30, April 2), and Each Drill Period</b>	<b>61</b>
C-1	W07US Dynamic Data, 2007 March 29 (JD# 88)–Fire Drill .....	62
C-2	W07US Dynamic Data, 2007 March 30 (JD# 89)–Simulated Bomb Threat Drill .....	70
C-3	W07US Dynamic Data, 2007 April 02 (JD# 92)–Simulated Airborne Chemical Release Drill .....	78

<b>Appendix D. Model representation of the 2007 April 2, Simulated Chemical Airborne Release Drill.</b>	<b>87</b>
<b>List of Symbols, Abbreviations, and Acronyms</b>	<b>107</b>
<b>Distribution List</b>	<b>109</b>

---

## List of Figures

---

Figure 1. The four stages of Consequence Management. ....	1
Figure 2. <i>W07US</i> Test Site layout—the black dots surrounding the partial 10-meter (m) towers were fence posts with telltale flags. ....	3
Figure 3. Wind tunnel studies show a repeatable airflow pattern around a single building. The streamline flow diagrammed is from left to right. The seventh flow feature, not seen in the figure, is a “canyon flow,” which is an accelerated flow between adjacent buildings (Snyder and Lawson, Jr., 1994). ....	6
Figure 4. Fire Drill Day (sonic data)—SW tower: (a) SW WD data; (b) SW WS data. ....	11
Figure 5. Fire Drill Day—Cavity flow examples (sonic data)—Southeast tower: (a) SE WD; (b) SE WS. ....	14
Figure 6. Simulated Bomb Threat Drill day (sonic data)—Southwest tower: (a) SW WD data; (b) SW WS data. ....	17
Figure 7. Simulated Bomb Threat Drill Day (sonic data)—(a) roof tripod WD data; (b) roof tripod WS data. ....	18
Figure 8. Simulated Bomb Threat Drill Day (sonic data)—Southeast tower: (a) SE WD data; (b) SE WS data. ....	20
Figure 9. Simulated Bomb Threat Drill Day (sonic data)—NE tower; (a) NE WD data; (b) NE WS data. ....	21
Figure 10. Simulated Airborne Chemical Release Drill Day (sonic data)—Southwest tower: (a) SW WD; (b) SW WS. ....	24
Figure 11. Simulated Airborne Chemical Release Drill Day (sonic data)—Northeast tower: (a) NE WD data; (b) NE WS data. ....	27
Figure 12. Simulated airborne chemical release specifications. ....	29
Figure B-1. SW tower: Solar radiation. ....	42
Figure B-2. SW tower: Pressure. ....	42
Figure B-3. SW tower: Temperature. ....	43
Figure B-4. SW tower: RH. ....	43
Figure B-5. SW tower: WS at 5-m AGL. ....	44
Figure B-6. SW tower: WD at 5-m AGL. ....	44
Figure B-7. SW tower: Thermodynamic data statistical summary for the Drill Days and Drill periods. ....	45
Figure B-8. Roof tripod: Net radiation. ....	46
Figure B-9. Roof tripod: Temperature. ....	46
Figure B-10. Roof tripod: WS at 6-m ArL. ....	47



Figure B-11. Roof tripod: WD at 6-m ArL.....	47
Figure B-12. Roof tripod: Thermodynamic data statistical summary for the Drill Days and Drill periods. ....	48
Figure B-13. NE tower: Solar radiation.....	49
Figure B-14. NE tower: Pressure.....	49
Figure B-15. NE tower: Temperature.....	50
Figure B-16. NE tower: RH.....	50
Figure B-17. NE tower: WS at 5-m AGL.....	51
Figure B-18. NE tower: WD at 5-m AGL.....	51
Figure B-19. NE tower: Thermodynamic data statistical summary for the Drill Days and Drill periods.....	52
Figure B-20. South tower: Solar radiation.....	53
Figure B-21. South tower: Pressure.....	53
Figure B-22. South tower: Temperature.....	54
Figure B-23. South tower: RH.....	54
Figure B-24. South tower: WS at 5-m AGL.....	55
Figure B-25. South tower: WD at 5-m AGL.....	55
Figure B-26. South tower: Thermodynamic data statistical summary for the Drill Days and Drill periods.....	56
Figure B-27. North tower: Solar radiation.....	57
Figure B-28. North tower: Pressure.....	57
Figure B-29. North tower: Temperature.....	58
Figure B-30. North tower: RH.....	58
Figure B-31. North tower: WS at 5-m AGL.....	59
Figure B-32. North tower: WD at 5-m AGL.....	59
Figure B-33. North tower: Thermodynamic data statistical summary for the Drill Days and Drill periods.....	60
Figure C-1. SW tower (Sonics): WS (March 29). ....	62
Figure C-2. SW tower (Sonics): WD (March 29).....	62
Figure C-3. SW tower (Sonics): Fire Drill Period–WS (March 29).....	63
Figure C-4. SW tower (Sonics): Fire Drill Period–WD (March 29). ....	63
Figure C-5. NE tower (Sonics): WS (March 29). ....	64
Figure C-6. NE tower (Sonics): WD (March 29). ....	64
Figure C-7. NE tower (Sonics): Fire Drill Period–WS (March 29).....	65
Figure C-8. NE tower (Sonics): Fire Drill Period–WD (March 29).....	65

Figure C-9. SE tower (Sonics): WS (March 29).....	66
Figure C-10. SE tower (Sonics): WD (March 29).....	66
Figure C-11. SE tower (Sonics): Fire Drill Period–WS (March 29) .....	67
Figure C-12. SE tower (Sonics): Fire Drill Period–WD (March 29).....	67
Figure C-13. RAZ tripods: WS (March 29).....	68
Figure C-14. RAZ tripods: WD (March 29).....	68
Figure C-15. RAZ tripods: Fire Drill Period–WS (March 29). ....	69
Figure C-16. RAZ tripods: Fire Drill Period–WD (March 29).....	69
Figure C-17. SW tower (Sonics): WS (March 30). ....	70
Figure C-18. SW tower (Sonics): WD (March 30).....	70
Figure C-19. SW tower (Sonics): Simulated bomb threat drill period–WS (March 30). ....	71
Figure C-20. SW tower (Sonics): Simulated bomb threat drill period–WD (March 30). ....	71
Figure C-21. NE tower (Sonics): WS (March 30).....	72
Figure C-22. NE tower (Sonics): WD (March 30). ....	72
Figure C-23. NE tower (Sonics): Simulated bomb threat drill period–WS (March 30).....	73
Figure C-24. NE tower (Sonics): Simulated bomb threat drill period–WD (March 30).....	73
Figure C-25. SE tower (Sonics): WS (March 30).....	74
Figure C-26. SE tower (Sonics): WD (March 30).....	74
Figure C-27. SE tower (Sonics): Simulated bomb threat drill period–WS (March 30). ....	75
Figure C-28. SE tower (Sonics): Simulated bomb threat drill period–WD (March 30).....	75
Figure C-29. RAZ tripods: WS (March 30).....	76
Figure C-30. RAZ tripods: WD (March 30).....	76
Figure C-31. RAZ tripods: Simulated bomb threat drill period I–WS (March 30) .....	77
Figure C-32. RAZ tripods: Simulated bomb threat drill period–WD (March 30).....	77
Figure C-33. SW tower (Sonics): WS (April 02). ....	78
Figure C-34. SW tower (Sonics): WD (April 02).....	78
Figure C-35. SW tower (Sonics): Simulated airborne chemical release drill period–WS (April 02). ....	79
Figure C-36. SW tower (Sonics): Simulated airborne chemical release drill period–WD (April 02). ....	79
Figure C-37. NE tower (Sonics): WS (April 02).....	80
Figure C-38. NE tower (Sonics): WD (April 02). ....	80
Figure C-39. NE tower (Sonics): Simulated airborne chemical release drill period–WS (April 02). ....	81

Figure C-40. NE tower (Sonics): Simulated airborne chemical release drill period–WD (April 02).	81
Figure C-41. SE tower (Sonics): WS (April 02).	82
Figure C-42. SE tower (Sonics): WD (April 02).	82
Figure C-43. SE tower (Sonics): Simulated airborne chemical release drill period–WS (April 02).	83
Figure C-44. SE tower (Sonics): Simulated airborne chemical release drill period–WD (April 02).	83
Figure C-45. RAZ: WS (April 02).	84
Figure C-46. RAZ: WD (April 02).	84
Figure C-47. RAZ: Simulated airborne chemical release drill period–WS (April 02).	85
Figure C-48. RAZ: Simulated airborne chemical release drill period–WD (April 02).	85
Figure D-1. Area of interest as discussed in section 5. The pink box identifies the subject building for this simulation.	88
Figure D-2. Simulated airborne chemical release threat description used by the ALOHA model.	89
Figure D-3. Minute # 1 of a 16-minute sequence of both wind flow and simulated chemical release footprints (sequence continues through figure D-18).	90
Figure D-4. Minute # 2 of a 16-min sequence of both wind flow and simulated chemical release footprints.	91
Figure D-5. Minute # 3 of a 16-min sequence of both wind flow and simulated chemical release footprints.	92
Figure D-6. Minute # 4 of a 16-min sequence of both wind flow and simulated chemical release footprints.	93
Figure D-7. Minute # 5 of a 16-min sequence of both wind flow and simulated chemical release footprints.	94
Figure D-8. Minute # 6 of a 16-min sequence of both wind flow and simulated chemical release footprints.	95
Figure D-9. Minute # 7 of a 16-min sequence of both wind flow and simulated chemical release footprints.	96
Figure D-10. Minute # 8 of a 16-min sequence of both wind flow and simulated chemical release footprints.	97
Figure D-11. Minute # 9 of a 16-min sequence of both wind flow and simulated chemical release footprints.	98
Figure D-12. Minute # 10 of a 16-min sequence of both wind flow and simulated chemical release footprints.	99
Figure D-13. Minute # 11 of a 16-min sequence of both wind flow and simulated chemical release footprints.	100

Figure D-14. Minute # 12 of a 16-min sequence of both wind flow and simulated chemical release footprints. ....	101
Figure D-15. Minute # 13 of a 16-minute sequence of both wind flow and simulated chemical release footprints. ....	102
Figure D-16. Minute # 14 of a 16-minute sequence of both wind flow and simulated chemical release footprints. ....	103
Figure D-17. Minute # 15 of a 16-min sequence of both wind flow and simulated chemical release footprints. ....	104
Figure D-18. Minute # 16 of a 16-min sequence of both wind flow and simulated chemical release footprints. ....	105
Figure D-19. A wind and plume representation based on 16-min averaged meteorological data input.....	106

---

## List of Tables

---

Table 1. Summary of the <i>W07US</i> Disaster Response Drills. Local Time is designated as “LT.” .....	2
Table 2. <i>W07US</i> dynamic (airflow) measurement information. ....	4
Table 3. <i>W07US</i> thermodynamic measurements acquired by Campbell CR23X micro-logger systems (Vaucher et al., 2007). ....	5
Table 4. <i>W07US</i> tower configuration.....	5
Table 5. <i>W07US</i> tower/tripod references and dynamic data (sonic) heights. ....	5
Table 6. Fire Drill wind profile averaged over the entire drill time period. ....	12
Table 7. 2007 March 30, “High Velocity” scenario statistics using the SW tower data at 10-m AGL. ....	17
Table 8. Maximum <i>W07US</i> temperatures for 2007 April 2.....	25
Table 9. Simulated Airborne Chemical Release Drill–2007 April 02. ....	26
Table B-1. Vertical distribution of thermodynamic data sampled from the <i>W07US</i> towers installed on the ground level only.....	41

---

## Acknowledgments

---

This study was made possible with the cooperative efforts of the *W07US* scientists, engineers, technicians and principle investigators. The author would, therefore, like to thank the entire *W07US* crew, as well as the Disaster Response Principle Investigators (Mr. Joseph Trammel and Ms. Felicia Chamberlain), the White Sands Missile Range (WSMR) Fire and Rescue Department (Chief Victor Lucero, Chief Vega) and the drill-participants/U.S. Army Research Laboratory (ARL) workforce (CISD, ADLO). She would also like to thank her supervisor, Dr. Donald Hoock, who provided consistent support, encouragement, and insights throughout the research experience; Mr. Saba “Lou” Lucas for his patent tutorial and brainstorming discussions. And finally, the ARL–WSMR Technical Editing staff, who are ARL’s critical link in creating high quality publications.

INTENTIONALLY LEFT BLANK.

---

## Executive Summary

---

This research is intended to calibrate the effectiveness of the 2007 U.S. Army Research Laboratory (ARL) safety procedures, by analyzing atmospheric measurements coincidentally sampled during three disaster response drills.

Each physical disaster is unique. Consequence Management Procedures and practical experience, such as the experience gained from executing controlled disaster response drills, have produced safety procedures, which help maximize a workforce's potential for survival. In 2007, the ARL conducted a detailed urban atmospheric study called the *White Sands Missile Range 2007 Urban Study*, or *W07US* for short. *W07US* investigated the airflow and stability around and above a single urban building. Coincident with this study were three disaster response drills. These drills consisted of a Simulated Fire/Smoke Release Drill, a Simulated Bomb Threat Drill and a Simulated Airborne Chemical Release/Shelter-In-Place (SIP) Drill. Due to visiting dignitaries, the smoke release was extracted from the Fire Drill, and executed on a separate day.

The *W07US* (Drill) test site consisted of a subject building surrounded on three sides by buildings of similar size and materials. The fourth side included a sidewalk, a 4-row parking lot and a 4-lane street. Thermodynamic and dynamic meteorological data were acquired on all sides of the subject building, as well as the roof. The data acquisition ran 24 hours a day/7 days a week (24/7) for about two weeks. Fifty-one sensors were used to sample Pressure, Temperature, Relative Humidity (RH), Wind Speed/Direction and Solar Radiation. The thermodynamic data were documented in 1-minute (min) averages; dynamic data were sampled at 20 hertz (Hz).

The Fire Drill required the subject building to be evacuated to a rally point northeast (NE) of the building. Pre-planned actions by six volunteer role players prompted a "search and rescue" effort from the participating emergency first response professionals. Two of these role players manifested their ailments at the rally point. The Fire Drill day was clear with temperatures between 4.3 and 18 degrees Celsius (°C), and low RH. Winds were a "Moderate Breeze" that decreased throughout the day to "Calm." During this drill, the winds transitioned from a west to a southerly, light breeze (2.0 meters per second [m/s]). Had smoke been present during the drill, the NE rally point would have been adequate for 38% of the time. During the balance of the time period, the location would have been challenged by the smoke. Alternate upwind rally points for the Fire Drill evacuation would have been northwest (35% of the time) and south (27% of the time) of the building.

The simulated bomb threat drill did not include a simulated explosion. However, since personnel were evacuated to a NE rally point, this location was assessed for safety. Accepting that surviving the initial blast at the rally point was wishful thinking, the analysis commenced by evaluating the impact of post-blast airflow-driven debris (dust/gas leaks/etc.) at the rally location. The atmospheric conditions for this day were sunny/clear in the morning, and partly cloudy in the afternoon. Temperatures ranged 5.4–18.4 °C. RH was high in the cool morning and dried throughout the day. During the drill, the westerly winds averaged 6 m/s. Examining the building's leeside measurements, the rally point was within the anticipated footprint for receiving added airborne hazards from a secondary plume. A better post-blast rally point would have been upwind or in this case, west of the subject building. A better pre-blast rally point would have been several kilometers upwind from the targeted site.

The Simulated Airborne Chemical Release Drill was the most educational event. The simulated airborne hazard was chlorine, accidentally released southeast (SE) of the subject building. As defined by the Test Plan, the workforce was instructed to report to the SIP location. The other option would have been to evacuate to the NE rally point. The atmospheric conditions for the drill day were clear, with warming temperatures and low RH. During the drill, the average temperature was 26.2 °C and RH was 9%. Winds were southwesterly at about 4 m/s. The building airflow was expected to produce a leeside cavity flow; however, the wind direction variations created a south-to-north channeling effect along the eastern side of the building, instead. The Test Plan requirement to SIP was correct, as per the coincident atmospheric conditions. Had the drill called for an evacuation to the NE rally point, the personnel would have encountered direct exposure to the airborne chemicals.

Two models were used to re-create the simulated chlorine incident. These models included: an ARL diagnostic wind field model called *Three-Dimensional Wind Field*<sup>\*</sup>, and an Environmental Prediction Agency (EPA)/National Oceanic and Atmospheric Association (NOAA) dispersion model called *Areal Locations of Hazardous Atmospheres* (ALOHA)<sup>†</sup>. Collating and animating the two sets of model output exposed several potentially vulnerable areas. Based on the wind fields, the main exit of the subject building and the fixed rally point would not have been “safe” areas, under the given atmospheric conditions of the drill. Referencing ALOHA's three-tiered plume concentrations and uncertainty curve output, there were only 2 min during which the rally point was free of potentially hazardous material.

Each drill did not involve hazardous materials. If the simulated incidents had, the workforce could have suffered ailments caused by un-informed decisions. The major lesson learned from this study was that decision makers need to be provided timely and relevant information

---

<sup>\*</sup> Wang, Y.; Williamson, C.; Garvey, D.; Chang, S.; Cogan, J. Application of a multigrid method to a mass consistent diagnostic wind model. *J App Meteorol* **2005**, *44*, 1078–1089.

<sup>†</sup> *ALOHA User's Manual*, The CAMEO Software System, EPA/NOAA, February 2007.



regarding ongoing hazardous incidents. Decision makers include the incident commander who manages the approach and resolution of the hazardous situation, the emergency first responders who work within the dynamic hazardous environment, the supervisors or building custodians that advise the workforce, and also, individuals that must make instantaneous self-preservation decisions.

The recommended “timely and relevant information required” include: the type of hazard threatening human life, the current condition of the environment during the hazard, and the best countermeasure/route-to-safety. To define the “hazard type” requires witnesses, chemical analysis sniffers and hazard source documentation. Assessing the “current hazard condition” necessitates a monitoring device that is able to continually characterize the environment. If this device could combine a projected hazard plume footprint with a visualization of current atmospheric conditions, the “best countermeasure/route-to-safety” would most likely become intuitive. Communicating the relevant hazard information to the appropriate decision makers, in a timely manner, is non-trivial. Contemporary technology is able to bring Web-type information to hand-held devices; therefore, one possible solution would be to create an approved situational awareness resource that would automatically transmit this timely information to the mobilized workforce and rescuer professionals.

**AUTHOR POSTSCRIPT:** One of the greatest rewards for research occurs when a study creates a positive impact on humanity. Through the quantitative measurements of the ARL urban field studies, urban modeling and subsequent data analyses, two significant safety products have come from this ongoing investigation:

1. The results from investigating the coincident disaster response drills and atmospheric conditions were communicated to the subject building safety personnel. In response, the participating workforce now has multiple rally points, which satisfy pre-defined safety regulations and are in keeping with the real-time “upwind” safety concept.
2. All three drills flagged the need for a timely and relevant situational awareness decision aid tool. Consequently, ARL has answered this “Lesson Learned” requirement by creating the “Local-Rapid Evaluation of Atmospheric Conditions (L-REAC<sup>TM</sup>) System.”<sup>‡</sup> This modular system provides authorized end-users near real-time 24/7 airflow maps around a subject building or region, and when applicable, a map of hazardous plume footprints over this same area. At the time of this publication, the L-REAC<sup>TM</sup> System development had completed the “Proof of Concept,” the Prototype and an Operational L-REAC<sup>TM</sup> System. The latter system had also successfully experienced its first “real world” event (the 2011 April Abrams Fire), verifying the value-added objectives motivating its development.

---

<sup>‡</sup> The L-REAC System trademark is owned by the Department of the Army, Washington DC, 20310.

Currently, the L-REAC<sup>™</sup> System is capable of communicating “live” results to building occupants, authorized emergency first responders and incident command decision makers in a timely manner. Details are described in section 9 of this report—*L-REAC<sup>™</sup> System, an Implemented Recommendation*.

---

## 1. Research Objective

---

This research is intended to calibrate the effectiveness of the 2007 U.S. Army Research Laboratory (ARL) safety procedures, by analyzing coincident atmospheric measurements sampled during three disaster response drills. These disaster response drills include: a Simulated Fire/Smoke Release Drill, a Simulated Bomb Threat Drill, and a Simulated Airborne Chemical Release Drill.

---

## 2. Background

---

When a physical disaster strikes a workforce, the workers respond as they are trained. This training is based on standards set by Consequence Management Procedures and practical experience. The four stages of Consequence Management Procedures include: Planning, Preparation, Response, and Recovery (see figure 1). The Planning Stage investigates the operational environment and involves deliberate site assessments. Meteorological tools utilized for these activities include local and regional climatology, as well as atmospheric models to simulate various potentially hazardous scenarios. The Preparation Stage includes monitoring activities, during which permanent meteorological resources linked to atmospheric models can be used to address specific emergency response interests. The Response Stage begins with a hazardous incident and concludes when the hazard is considered contained or under control. The final stage is the Recovery Stage. Both the Response and the Recovery Stages utilize real-time weather intelligence. The impact of the weather information during the Recovery Stage is somewhat reduced, due to the imminent return to normal conditions associated with this last stage (*Multiservice Tactics . . . etc.*, 2008).

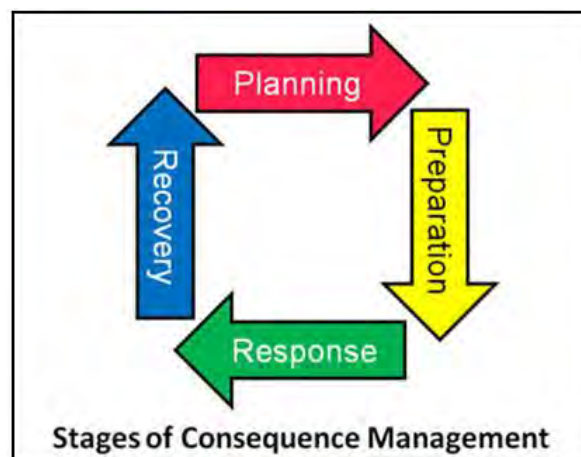


Figure 1. The four stages of Consequence Management.

Practical experience for responding to physical disasters often manifests as lessons learned after an incident occurs. However, the recovery after an actual incident could include human death and suffering. A more benign method for gaining this practical experience, however, is to create simulated disasters for the workforce to respond to, along with coincident in situ atmospheric measurements to calibrate the accuracy or appropriateness of human response training. Elements from all four Consequence Management stages are required to plan, prepare and execute such a simulated event. In 2007, a controlled “practical experience” was implemented by ARL at White Sands Missile Range (WSMR), NM. Atmospheric scientists, risk management and security professionals combined detailed atmospheric measurements with the mandatory annual safety training. This report documents some of the results gleaned from an analysis of the coincident atmospheric measurements and the disaster response simulation drills.

## 2.1 WSMR 2007 Urban Study (W07US) Field Study and Disaster Response Drills

ARL conducted three, 1–2 week long *WSMR Urban Studies* between March 2003 and April 2007. Each *Study* focused on the airflow and stability characteristics around a single urban building. The last field study, *W07US* was executed in 2007 March–April. Unlike the earlier *Studies*, this detailed scientific urban atmospheric investigation included a research application objective. The specific application objective was:

“To demonstrate disaster response applications for scenarios focused on a single office building.” (Vaucher, 2006)

Three disaster response drills, involving simulated airborne threat scenarios to a workforce, fulfilled the objective. These drills are summarized in table 1. A detailed description of each drill will be presented in later sections.

Table 1. Summary of the *W07US* Disaster Response Drills. Local Time is designated as “LT.”

<b>W07US Drill (2007)</b>	<b>Civilian Hazard</b>	<b>Date (dd-month)</b>	<b>Start Time (LT)</b>	<b>End Time (LT)</b>
Simulate Fire Drill	Smoke Plume / Extreme Convection	29-Mar	1315	1425
Smoke Release	Smoke Plume	28-Mar	1330	1600
Simulated Bomb Threat Drill	Airborne Debris	30-Mar	1300	1345
Simulated Airborne Chemical Release Drill/Shelter-In-Place (SIP)	Chemical Plume	2-Apr	1305	1320

Two Post-*W07US* Test Plan goals converted the drill experience into practical lessons learned. These were: (1) to evaluate the executed civilian response procedures against coincident atmospheric data, and (2) to offer recommendations based on an informed understanding. To better understand the lessons learned, a description of the *W07US* Field Test Site follows.

## 2.2 W07US Field Test Site

The *W07US* Test Site consisted of a subject building that was a rectangular, two-story tall office building with a nearly flat roof. To the north and south of this subject building were similarly shaped and constructed buildings, having two and one story heights, respectively. Between these buildings were nearly level gravel and dirt surfaces. To the east were a small, tailored grassy area; a four-row parking lot with a dividing walkway between rows two and three; and a four-lane road. No vehicles were permitted in the parking areas during the data acquisition period. Figure 2 displays a plan view of the *W07US* building domain.

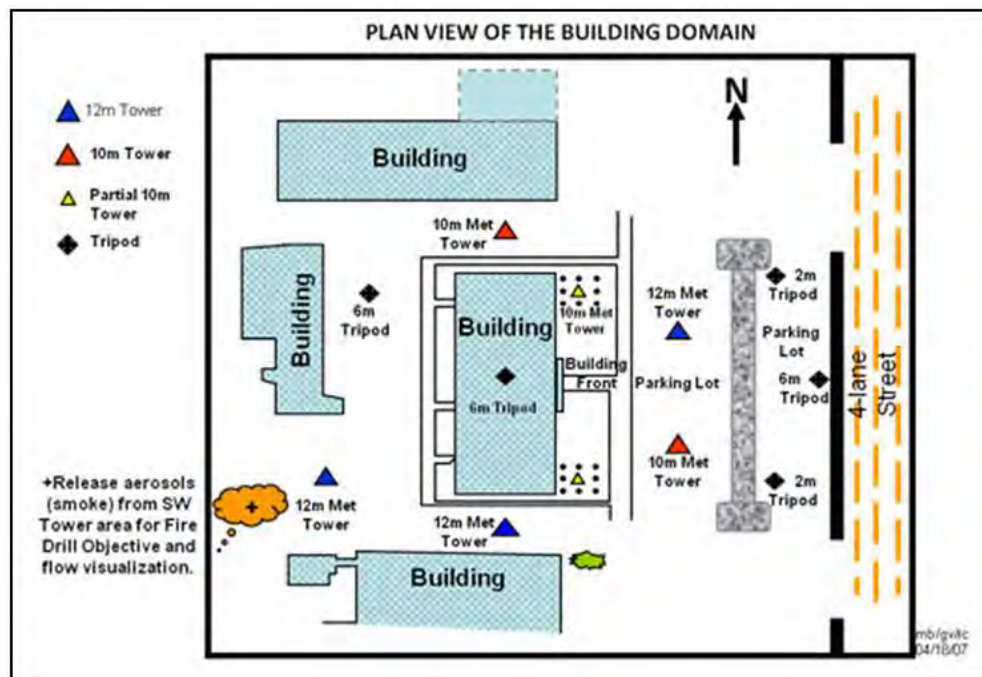


Figure 2. *W07US* Test Site layout—the black dots surrounding the partial 10-meter (m) towers were fence posts with telltale flags.

## 2.3 W07US Atmospheric Data

The *W07US* atmospheric data resources are described in several technical reports, including:

- ARL-TR-4255 (Vol.1): *W07US* Overview of Design, Preparations, and Field Study Execution (Vaucher, et al., 2007).
- ARL-TR-4439 (Vol. DP-1): Data Processing—Pre- and Post-*W07US* Sonic Calibration (Vaucher, et al., 2008a).
- ARL-TR-4440 (Vol. DP-2): Data Processing—Main Dataset (Vaucher et al., 2008b).
- ARL-TR-4441 (Vol. DP-3): Data Processing—Airflow Qualitative Assessment (Vaucher et al., 2008c).

- ARL-TR-4456 (Vol. AS-1): Atmospheric Stability–Comparing Stable Patterns from Two Similar Urban Field Studies (Vaucher, 2007a).
- ARL-TR-4452 (Vol. AS-2): Atmospheric Stability–Stability Qualitative Assessment, and Inter-Studies Comparison (Vaucher et al., 2008d).
- ARL-TR-4954 (Vol. AS-3): Atmospheric Stability–Urban Versus Rural Diurnal Stability Cycles (Vaucher, 2009).

The following briefly summarizes the *W07US* dataset attributes, which are most relevant to the disaster response drills.

### 2.3.1 Data Locations

The *W07US* field design required mounting fifty-one atmospheric sensors on twelve towers/tripods around a subject building (see figure 2). In figure 2, compass north is at the top of the page. The triangles represent the three tower types: 12- (blue), 10- (red), and partial 10-m (yellow) towers. The black crosses indicate the 6- and 2-m tripods. The black dots, surrounding the partial towers on the east (leeside) of the subject building, were fence post positions. Flags were attached to each fence post, to enable a real time visualization of the horizontal circular airflow in that region. The initial location for the smoke release is marked with a cloud-like symbol. The regional climatology indicates that the prevailing wind was westerly (left to right). However, the test site’s local climatology indicated a prevailing wind flow that went from the southwest (SW) to the northeast (NE); thus, the major towers have a slightly skewed orientation.

### 2.3.2 Data Types

The atmospheric sensors were subdivided into dynamic and thermodynamic groups, based on their primary function in the scientific analysis. The 25 dynamic sensors were RM Young Ultrasonic (sonic) Anemometers, and were mounted on the west (windward) side of the towers (table 2). The primary variables measured were wind speed (WS) and wind direction (WD).

Table 2. *W07US* dynamic (airflow) measurement information.

Variables	Sensor	Manufacturer	Model
Wind-component vectors, WS/WD, temperature, speed of sound	Ultrasonic anemometer	RM Young	81000
Wind direction: Located on the NE and southeast (SE) building corners	Fence post with flag on top	—	—

The 26 thermodynamic sensors were linked to five Campbell 23X micro-loggers, and were positioned on the east (sunrise/leeside) and south sides of the towers/tripod. The variables sampled are listed in table 3. The full *W07US* tower/tripod configuration utilized for both the dynamic (sonic) and thermodynamic (Campbell systems) groups are summarized in table 4.

Table 3. *W07US* thermodynamic measurements acquired by Campbell CR23X micro-logger systems (Vaucher et al., 2007).

Variable	Sensor	Manufacturer	Model	Units
Pressure	Barometer	Vaisala	PTB-101B	Millibars (mb)
Temperature	Thermometer	Campbell	T107	Celsius
Temperature/Relative humidity (RH)	Thermometer/Hygrometer	Vaisala	HMP45AC	Celsius/ Percent
WS and WD	Wind monitor	RM Young	05103	Meter/second and degrees
Solar radiation	Pyranometer	Kipp/Zonen	CM3	Watts/meter <sup>2</sup>
Net solar radiation	Net radiometer	Kipp/Zonen	NR-LITE	Watts/meter <sup>2</sup>

Each tower was labeled by the compass position with respect to the subject building. For example, the North tower was north of the subject building. The SE tower was SE of the subject building. Partial towers and tripods were labeled according to the airflow feature being captured and the compass location around the building. For example, the three tripods to the east of the building were called, “Re-attachment Zone-North,” “Re-attachment Zone-East,” and “Re-attachment Zone-South.” For a complete tower/tripod reference list, see table 5.

Table 4. *W07US* tower configuration.

Tower	Number of Units	Sensors: Sonics (/unit)	System: Campbell (/unit)
12-m tower	3	3 per unit	1 per unit
10-m tower	2	2 per unit	1. North: 1 2. Southeast: 0
Partial tower	2	1. Northeast: 2 2. Southeast: 3	0
6-m tripod	3	1. Roof: 1 2, 3. NWC, RE <sup>a</sup> : 2	1. Roof: 1 2, 3. NWC, RE <sup>a</sup> : 0
2-m tripod	2	1 per unit	0
Totals	12	25 sonic sensors	5 Campbell systems

<sup>a</sup> NWC = northwest canyon; RE = re-attachment-east zone.

Table 5. *W07US* tower/tripod references and dynamic data (sonic) heights.

Reference	Tower/Tripod	Sonic Heights
SW	12-m tower	2.5, 5, 10 m
South	12-m tower	2.5, 5, 10 m
Northeast	12-m tower	2.5, 5, 10 m
North	10-m tower	2.5, 10 m
Southeast	10-m tower	2.5, 10 m
Roof	6-m tripod	6 m
Re-attachment-North	6-m tripod	2.5 m
Re-attachment-East	6- m tripod	2.5, 5 m
Re-attachment-South	6-m tripod	2.5 m
Leeside Corner Eddy/Vortex-North	10-m partial tower	2.5 east, 2.5 west
Leeside Corner Eddy/Vortex-South	10-m partial tower	2.5 east, 2.5 west, 5 m
Canyon-Northwest	10-m partial tower	2.5, 5 m

### 2.3.3 Data Time Series

A graphical time series of all five of the thermodynamic data variables for 2007 March 28–April 2 (Julian day [JD]# 87-92) is given in appendix B. These 1-minute (min) average plots were utilized for describing the diurnal weather conditions, as well as some of the local forcing effects. The dynamic data time series, sampled at 20 hertz (Hz) by sonic anemometers, are presented by drill in chronological order in appendix C. Topic-specific samples of the time series were extracted and placed within the main report, as needed. The dynamic data series was originally sampled at 20 Hz; however, to help ease the interpretation, they have been reduced to 1-min averages that are aligned with the thermodynamic dataset.

Before utilizing the two datasets to interpret the atmospheric conditions, there are some important notes that need to be flagged: (1) *Solar Radiation*—Building and local obstacle shadows caused temporary data gaps in the solar radiometer data time series. Towers west of the subject building showed such gaps around sunrise, whereas eastside towers showed these “holes” near sundown. Only the roof’s radiometer was immune to these local effects. (2) *Winds*—The thermodynamic WS and WD were taken at 5-m above ground level (AGL). The dynamic winds were sampled at 2.5-, 5-, and/or 10-m AGL. The Roof tower wind data were sampled at 6-m above roof level (ArL). The vertical wind profile of the sonic winds measured a slight acceleration with height. This characteristic was expected, since there was less friction aloft than near the surface. The wind orientation was largely a function of the local forcing effects. (3) *Building Flow Features*—The presence of seven distinct building airflow features, as defined by the 1994 Environmental Protection Agency (EPA)/National Oceanic and Atmospheric Administration (NOAA) wind tunnel study, was evident during the drills (Snyder and Lawson, Jr, 1994). Figure 3 labels these seven patterns where they occur with respect to a building structure. These features will be flagged, as they relate to the analysis.

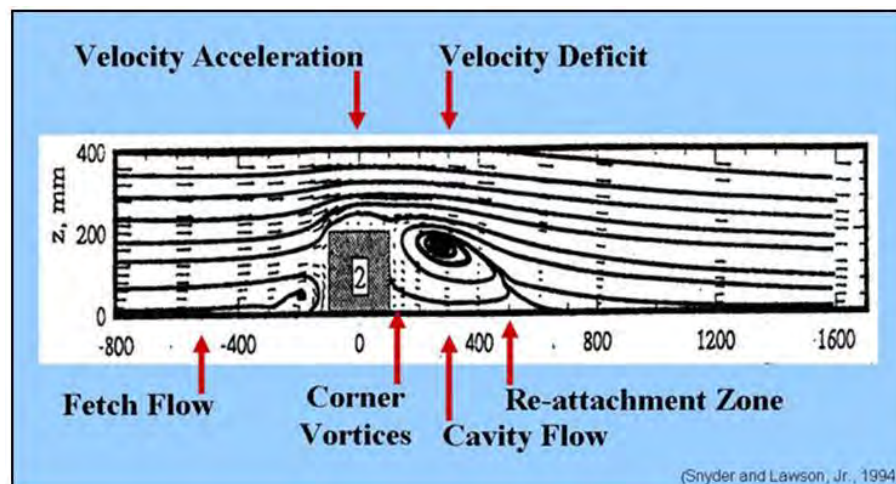


Figure 3. Wind tunnel studies show a repeatable airflow pattern around a single building. The streamline flow diagrammed is from left to right. The seventh flow feature, not seen in the figure, is a “canyon flow,” which is an accelerated flow between adjacent buildings (Snyder and Lawson, Jr., 1994).



### 2.3.4 Data Analysis Resources

Each drill day was characterized by the atmospheric conditions observed over the 24-hour (h) period during which a drill occurred. A summary of the atmospheric conditions during the actual drill period completes the atmospheric description.

The prevailing WD for the urban study site was southwesterly. After verifying the prevailing WD for the specific drill day, statistics were calculated using this “fetch” or SW tower data. When this tower resource had to be varied, a note in the description section was made.

The four-dimensional data sampling described above provided an extensive resource for a quantified atmospheric analysis. However, to evolve the point sampling into an area map of atmospheric and airborne hazard conditions, two models were required. The ARL *Three Dimensional Wind Flow* (3DWF) Model was used to represent the wind flow around the buildings (Wang et al., 2005). As a separate function, the EPA/NOAA *Areal Locations of Hazardous Atmospherics* (ALOHA) Model generated a hazardous plume and overlaid it onto a given map (*ALOHA User's Manual*, 2007).

Both models presume that their atmospheric input is representative of the area in question. For 3DWF, the best representative vertical wind profile would be from the subject building's fetch or upwind meteorological data tower.

The ALOHA model would ideally have its input data sampled from the scene of the incident (toxic release). When this information is unknown or un-attainable, an alternate choice would be an area-representative sampling. Again, the subject building's fetch or upwind meteorological data tower falls into this category. Consequently, most of the analysis will begin by referencing the data from the upwind meteorological tower. Since prevailing winds for the area are from the SW, the primary resource for analysis will be the SW tower.

The single value (versus profile) wind input required by ALOHA was taken from the 10-m AGL sensor. Pre-analysis of the *W07US* vertical profiles surrounding the subject building established that local forcing effects strongly impacted the wind measurements, especially in the near-surface samples. Thus, fetch data acquired furthest from the ground (10-m AGL) were used for single measurement input.

When winds are light and variable, and an in situ incident measurement was not available, the fetch resource was changed to the Roof tower. The typical velocity acceleration over the roof was kept in mind. However, at such low velocities (light and variable) this biasing was presumed to be minimal.

Finally, since winds were a key input for the drill analysis, to help envision the effects of the airflow magnitudes, the Beaufort wind force scale descriptors were referenced. For further information on these descriptors, see Met Office, Beaufort Wind Force Scale (2010).

---

### 3. Fire Drill and Smoke Release

---

The original Test Plan-Fire Drill called for a coincident Fire Drill and Smoke Release to occur. Due to non-*W07US* events, these activities were re-scheduled for two separate days. Consequently, the Fire Drill and Smoke Release will be described separately, in section 3.1 and appendix A, respectively.

#### 3.1 Fire Drill Activities

The following paragraphs summarize the Fire Drill activities. Note that all victims described were volunteer role players from within the ARL workforce.

The Fire Drill occurred on Thursday, 2007 March 29 (JD# 88) and was directed by the *W07US* Disaster Response Principle Investigator (PI). Early in the day, the Disaster Response PI issued a notice to the work force informing them of the impending drill. The Fire Drill began with two preparation meetings. The first included a discussion between the PI, the lead rescue persons and the six voluntary victims. This meeting clarified the key action items and responses expected. The second meeting just prior to the event allowed the key players and the video person to briefly review their actions and survey the area for any miscellaneous items needing attention. One item, a vehicle parked on the west side of the subject building was an impediment and was moved. Once completed, the PI and Fire Chief initiated the fire alarm.

The subject building fire alarm went off at approximately 1315 Mountain Time (MT), as scheduled. All ARL and contractor persons in the building evacuated to the NE corner of the parking lot (as per their training). Several persons were quickly identified as missing. The Fire Inspector and Safety Officer conducted searches on all floors. A “Chicken Little” victim was found inside his office stating he could not leave until everything was turned off and secured. Orders were issued to evacuate the building immediately and meet at the evacuation point.

The Safety Officer requested a second personnel accountability update from the building Fire Warden, who identified three missing employees and stated their assigned office locations. The Fire Chief relayed this information to the fire crew inside the subject building.

A wheelchair victim was found on the second floor negotiating an elevator/stairs evacuation. A second “assisted” victim was a claustrophobic colleague who had gotten stuck in the elevator while trying to bring the elevator to the wheelchair person. The WSMR Fire/Rescue crew quickly and calmly assisted both handicapped victims down the stairwell and out of the SW exit of the building. Simulated oxygen was applied to each victim as they sat at a safe distance on the SW side of the building. A triage of the medical ailments by the First Responder professionals defined the simulated first aid given to the victims until this portion of the drill was completed.

Concurrently with the handicap victim events, the Fire Inspector and Safety Officer re-entered the subject building from the northwest side and descended into the basement calling out the names of the missing persons. A third victim opened a solid lab door explaining that he had not heard the alarm. They escorted him out of the SW rear door where he joined the two assisted victims. All three victims were declared healed and fit for duty. The Safety Officer then escorted the three rescued-victims to the other workforce colleagues waiting at the NE evacuation point.

With all evacuated persons present, a heart attack victim suddenly fell to the pavement. Near-by colleagues assisted the victim while the safety officer phoned to report the incident. The first aid crew arrived and proceeded to employ the standard heart attack countermeasures. As they worked, various persons working on the patient explained the first aid procedures to the evacuated onlookers. Once that portion of the drill concluded, viewer questions were addressed.

The final victim (who reported the effects of an acid spill on his hand) surfaced as the first aid crew was collecting their heart monitoring equipment from the revived heart attack victim. The wound was addressed and the activity portion of the drill was completed.

The PI concluded the drill by directing the evacuated persons to a Conference Room for a Safety Stand-down Day debrief. The WSMR Building Inspector and Assistant Fire Chief explained priorities during a fire drill, offered suggestions for identifying the best exit when evacuating, and identified the subject building's type with its consequential fire concerns. The guest speakers also outlined the standard procedure for their fire/rescue crews when dealing with a building on fire, and answered questions from the audience. The safety debriefing concluded at 1425 MT (Vaucher, 2007a).<sup>§</sup>

### **3.2 General Atmospheric Conditions on the Fire Drill Day**

The Fire Drill day was clear, as shown in all five solar radiometer acquisition locations for JD# 88/2007 March 29 (see appendix B). A cold upper level low over Colorado and northern New Mexico kept the regional temperatures below normal. The average local temperature for this day was about 10 degrees Celsius (°C). The min/max temperature extremes were 4.3 °C (North tower at 0353 LT) and 18 °C (Roof tower at 1558 LT), respectively. WD was primarily westerly (west-northwest) for about 75% of the day [see figure 4 (a) and (b)]. Between 1200–1759 LT, the winds made a distinct shift, and became southerly. The SW tower was positioned to receive a relatively uninterrupted flow from both west and south directions; therefore, the rest of the general weather summary for this date will be based on the SW tower only:

---

<sup>§</sup> Notes taken by W07US Test Director-Vaucher and Risk Management/Safety Officer-Chamberlain.

The near surface (2.5-m AGL) average RH was 22% ( $\pm 8$ ). Winds at 10-m AGL ranged from a Moderate Breeze of 7.0 meters per second (m/s) (at 0020 LT) to Calm (0.2 m/s) at 1508 LT. The general WS trend over the 24-h cycle was toward decreasing velocities. During the 6-h period of southerly flow, the average WS at 10-m AGL was  $2.1 \pm 1.1$  m/s (which is between Light Air and Light Breeze on the Beaufort Scale).

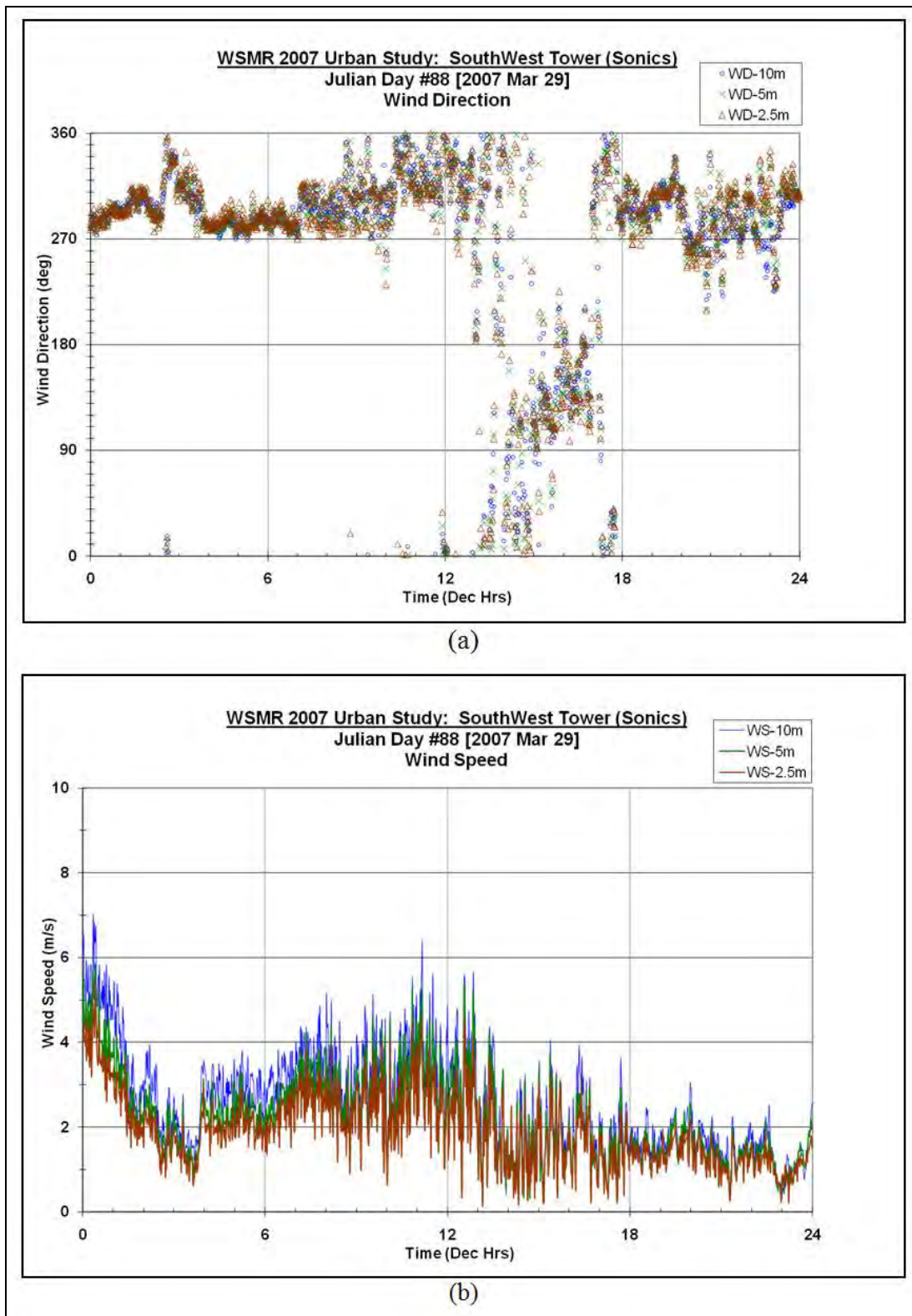


Figure 4. Fire Drill Day (sonic data)–SW tower: (a) SW WD data; (b) SW WS data.

### 3.3 Measured Atmospheric Data during the Fire Drill

The Fire Drill period (1315–1425 LT) occurred just as the dominant airflow direction initiated a distinct shift to southerly. During the actual drill, the winds were from the south 27% of the time. For 35% of the time, they were from the northwest; and for 38% of the time, they were from the NE. Since the predominant WD over this time period was shifting from westerly to southerly, the event’s representative meteorological data were taken from the SW tower. This choice coincides with the original *W07US* field design that labeled the SW tower as the upwind or fetch location for the site. As an independent verification for the event’s characterizing WD, the coincident roof tripod data were also consulted. The data measured from the Roof tower confirmed a wind shift to southerly airflow that aligned with the southwestern tower data.

Based on the southwestern tower data: The atmospheric conditions during the 70-min Fire Drill were characterized as clear with 877 watts per square meter ( $\text{W/m}^2$ ) of solar radiation, and a southerly “light breeze” of  $2.0 (\pm 1.1)$  m/s at 10-m AGL. The full vertical sonic wind profile sampled is in table 6. Temperatures over the Fire Drill time period were between 14.5 and 15.4 °C. RH averaged 13.4%. Appendix C-1 displays a time series of the Fire Drill winds sampled at the SW tower.

Table 6. Fire Drill wind profile averaged over the entire drill time period.

Southwest Tower				
Fire Drill–29 March	Averaged	±Std Dev*	Averaged	±Std Dev
1315–1425 LT	WS (m/s)	WS (m/s)	WD (deg)*	WD (deg)
10 m–sonic # 1360	2.0	1.1	176	127
5 m–sonic #1358	1.8	0.9	186	132
2.5 m–sonic # 1359	1.6	0.8	203	130

\* Std Dev = Standard Deviation; deg = degrees (unit)

### 3.4 Safety Drill Observations

Two primary questions were raised during the analysis:

- (1) Based on the atmospheric conditions, how safe was the rally point?
- (2) What were the lessons learned from the experience?

A summary of the findings are given in the subsequent sections.

#### 3.4.1 Was the Rally Point Safe?

All personnel not role-playing, evacuated the subject building to the NE corner of the parking lot in a timely manner, resulting in a notably efficient, personnel accountability. Had this situation been a real fire, however, the smoke from the fire would have flowed from south to north for 27% of the time. With such low wind velocities around the subject building, the smoke would have potentially loitered north of the building, challenging the safety of the NE rally point.

Most humans will instinctively retreat from a hazardous location. The question becomes, where would they have gone? Conducting personnel accountability is the second most important goal while evacuating during a fire (first being—to get out of the hazardous area). If people had randomly scattered to their own self-determined safe locations, the ability to identify missing or injured persons to the emergency first responders would have become nearly impossible.

### **3.4.2 Was the Search/Rescue Re-entry Point Safe?**

Once the missing persons were identified, the Fire Chief and Safety Officer re-entered the building from the northwest side. For the drill, this action was acceptable. If smoke were present, however, the northwest side might have been inaccessible due to the hazard. Without a method for envisioning the smoke, the drill participants could not have known they were endangering themselves. Taking this observation to a “what if”: Had the hazard been an invisible plume (such as carbon monoxide), how would the search and rescue personnel (who in this case were the Fire Chief and Safety Officer) have known where to safely re-enter the building? The lesson learned: There is a need for mapping near real-time hazard locations, and also communicating this information in a timely manner to the onsite personnel (i.e., search and rescue crews).

### **3.4.3 Mandatory versus Training Rally Points**

Regulations require evacuated personnel to rally at a pre-defined minimal distance from a building. The assembling point used during the drill was closer to the building to keep personnel from having to cross a four-lane road, which the fire trucks were expected to concurrently traverse. This action prevented the unnecessary endangerment of the rehearsing workforce. However, for a real fire, the mandatory rally point requirement forcing personnel to cross a four-lane street needs to be addressed. This hazard was not a weather-related concern, yet the observation is noted here for record.

### **3.4.4 What if the Drill had Occurred during the Prevailing Westerly Winds?**

For nearly 75% of the Fire Drill day, winds were westerly. Under these conditions, the potential for a well-formed cavity flow feature increases. Figures 5 (a) and (b) (WD and WS, respectively) displays the easy to recognize cases recorded in the SE tower data. Note that the upper level (10-m AGL) winds are westerly (blue dots), the coincident wind flow sampled at 2.5-m AGL is easterly. The mid-level is random. The significance of this cavity flow is that the WD change draws air back into the building (flow reversal). Coupling the rotor pattern with a slower velocity at the low level, any toxins released into this area would have an increased potential for becoming trapped within the cavity flow feature. The close proximity of this leeside cavity flow feature and the rally point would have created a less than safe environment for the NE rally location. However, if personnel complied with the required distance from the building, crossing the large road, the environment would have been significantly less hazardous.

This cavity flow feature did dissolve when the winds shifted to southerly, which flags an important lesson learned. That is, timely and relevant atmospheric condition intelligence is critical to ensuring effective decision makers.

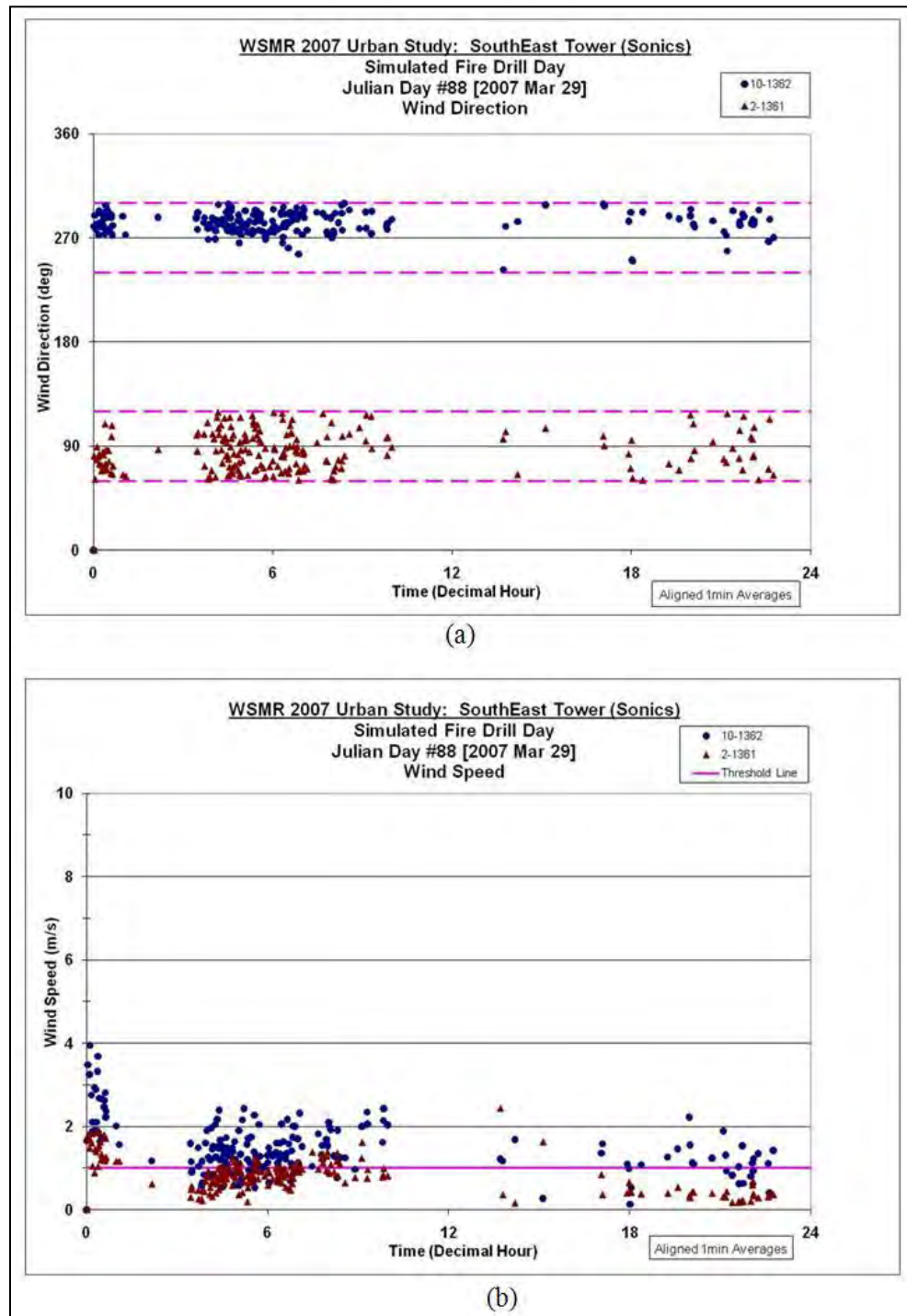


Figure 5. Fire Drill Day–Cavity flow examples (sonic data)–Southeast tower: (a) SE WD; (b) SE WS.



---

## 4. Simulated Bomb Threat

---

A Simulated Bomb Threat is not an airborne event unless the simulation includes an explosion. With a detonation, there are several elements that involve the atmosphere, each with varying time durations: a sudden burst of heat, fire fueled by building resources, flying debris and the potential for secondary gas releases (*ALOHA User's Manual*, 2007). The *W07US* Simulated Bomb Threat Drill did *NOT* include an explosion; however, for this report, we will presume there was an explosion *AFTER* all personnel were evacuated from the building, and that all personnel were able to survive this initial blast. Thus, the analysis focus will be on the secondary airborne debris being steered by the dominant local wind pattern(s).

### 4.1 Simulated Bomb Threat Drill Activities

The following paragraphs summarize the Simulated Bomb Threat Drill:

The Simulated Bomb Threat Drill occurred on Friday, 2007 March 30 around the *W07US* subject building. The Simulated Bomb Threat phone call was received by a supervisor at approximately 1300 MT. Following the standard Bomb Threat Checklist, the supervisor determined the pertinent details of the threat. Notification of the phone call was immediately conveyed to security, who issued a warning through proper channels to the entire workforce at 1306 MT. Under supervisor guidance, designated employees simultaneously “swept” all floors, informing workers of the threat and their need to evacuate. A general information screen in the building lobby was manually switched to a screen informing the building occupants of the in-progress, simulated bomb threat drill. Note: This response action was the first time the building display was utilized for communicating “emergency” status information for a real-time event.

As per instructions, a designated subset of employees met security at a predetermined location. This small group then walked to the targeted site and began to conduct a systematic search for the simulated bomb. The room was informally divided into three parts. Immediately, a white bag with wires in the front was spotted and tagged as unusual. This item was not the simulated bomb. The survey continued with the searchers taking different parts of the room. With this first rotation of room parts, the simulated bomb was located under a podium and confirmed by the other searchers.

The searchers then turned over subsequent actions to the local bomb threat professional and joined the evacuated persons in the NE parking lot. Outside, an additional search was conducted and an unusually placed lunch bag was identified as suspicious. The Security Drill-Lead confirmed the suspicion to be the last simulated bomb threat of the drill.

All the evacuated persons were allowed to re-enter the building, where a debriefing was conducted by the drill's PI. The inside and outside scenarios were reviewed and each simulated bomb was plainly shown with the contents exposed to the viewers. After a brief question and answer session, the drill was declared completed; time was 1345 MT (Vaucher, 2007b).<sup>\*\*</sup>

## **4.2 General Atmospheric Conditions on the Simulated Bomb Threat Day**

The atmospheric conditions, for 2007 March 30 (JD #89) were sunny/clear in the morning and partly cloudy in the afternoon. An atmospheric shortwave traveling around the upper level low pressure over Colorado and New Mexico, coupled with a surface cold front moving through the area of interest (AOI), prompted the afternoon clouds. These two sources of lift provided the cloud cover evolution, but lacked sufficient energy for local shower activity.

Locally, the extreme minimum and maximum temperatures were 5.4 °C (North tower, 10-m AGL at 2357 LT) and 18.4 °C (North tower, 2.5-m AGL at 1057 LT), respectively. The average (10-m AGL, SW tower) temperature for this day was 10.7 °C. Surface RH began the day with a typical diurnal moist pattern. However, from 1200 to 2318 LT, the surface RH made a persistent increase between 14 and 63% (the day's maximum).

Over the 24-h period, there were two dominant airflow scenarios—low velocity winds (Calm to Gentle Breeze) and high velocity winds (Light Breeze to Fresh Breeze). The first scenario ran from 0000 to 0859 LT, then resumed from 1900 to 2359 LT. The cumulative averaged velocity for these two “low velocity” time periods was 1.5 m/s. Visually interpolating the time series, the WD tended to be northwesterly.

The 10 remaining hours of “high velocity” winds (0900–1859 MT) can be subdivided into three parts, based on their respective dominant WDs. Using the SW and Roof tower sonic wind data [see figures 6 (a) (b) and 7 (a) (b)]:

From 0900 to 1059 LT, the dominant WD was southeasterly.

From 1100 to 1359 LT, winds were westerly.

From 1400 to 1859 LT, winds were northeasterly.

Each shift was a fairly abrupt, distinct change. Table 7 shows the statistical WS/WD averages and their WS minimum/maximum velocities for the three sub-periods:

---

<sup>\*\*</sup> Notes taken by W07US Test Director-Vaucher.

Table 7. 2007 March 30, “High Velocity” scenario statistics using the SW tower data at 10-m AGL.

2007 Mar 30 Time Period (LT)	Averaged WS (m/s)	Averaged WD (deg)	Minimum WS (m/s)	Maximum WS (m/s)
0900–1059 h	4.4 ( $\pm 1.1$ )	145 ( $\pm 15$ )	2.1	8.0
1100–1359 h	5.5 ( $\pm 1.5$ )	266 ( $\pm 28$ )	1.0	9.8
1400–1859 h	5.3 ( $\pm 1.7$ )	17 ( $\pm 43$ )	0.2	9.0

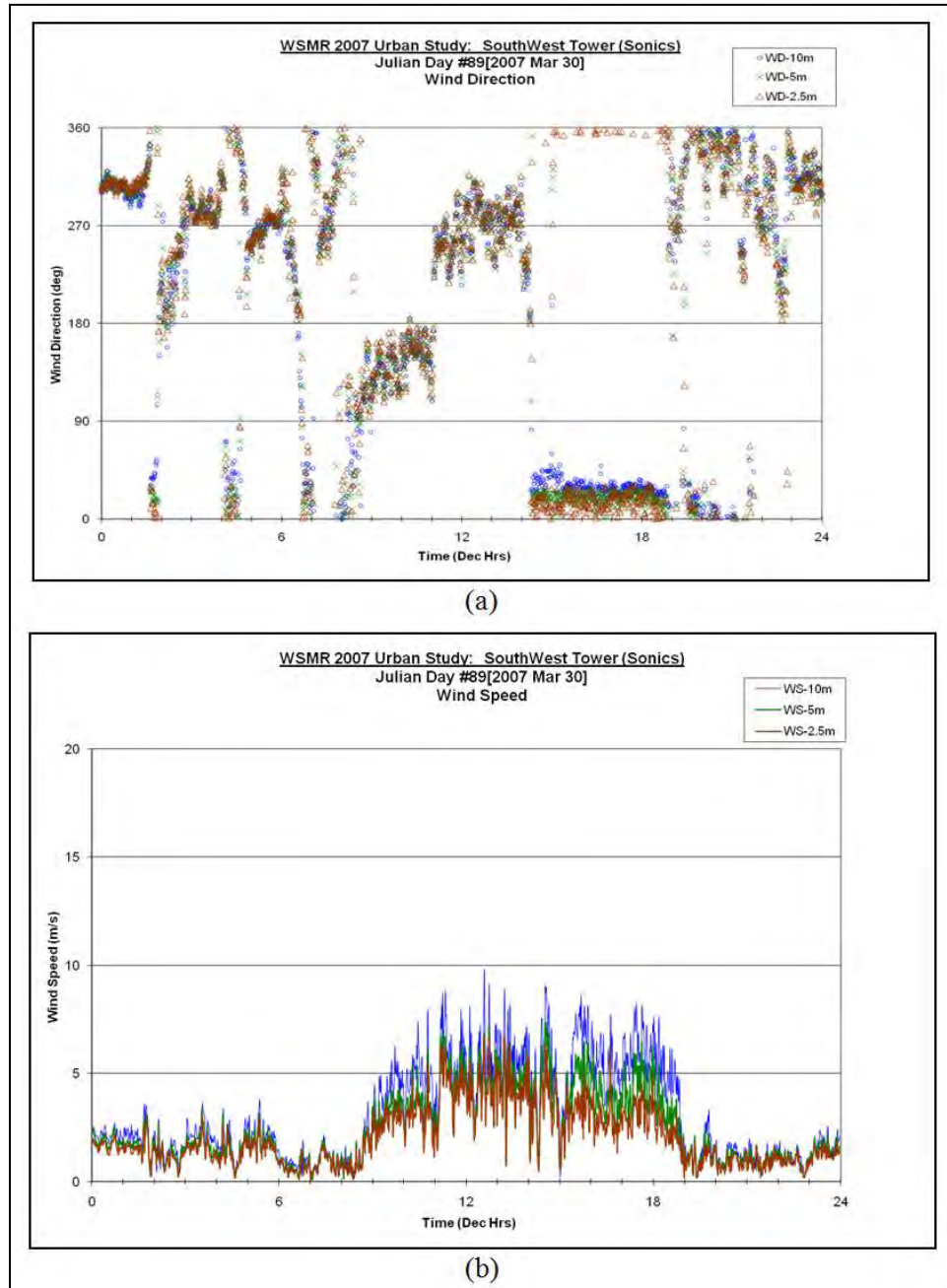


Figure 6. Simulated Bomb Threat Drill day (sonic data)–Southwest tower: (a) SW WD data; (b) SW WS data.

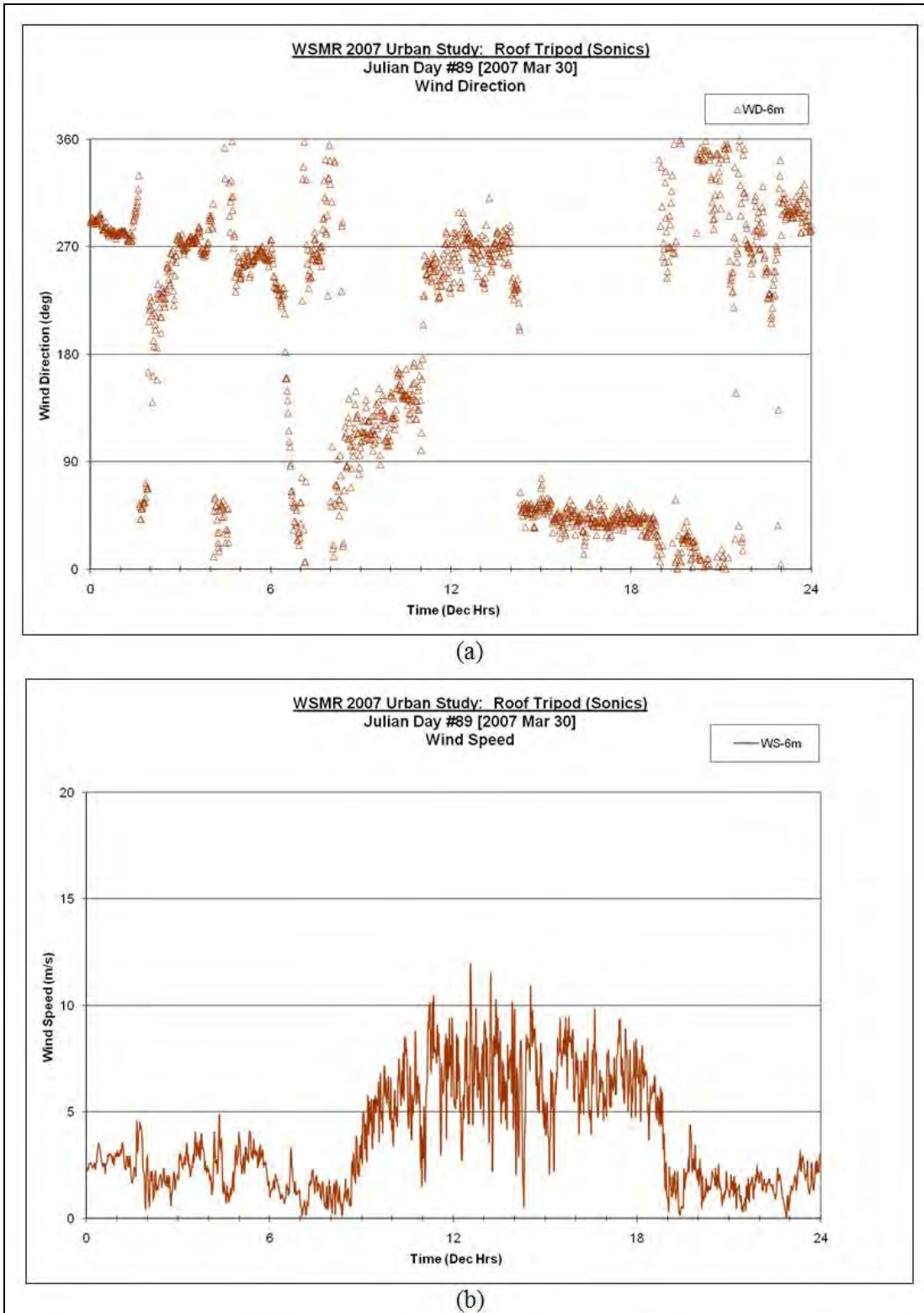


Figure 7. Simulated Bomb Threat Drill Day (sonic data)—(a) roof tripod WD data; (b) roof tripod WS data.

### **4.3 Measured Atmospheric Data during the Simulated Bomb Threat Drill**

The 2007 March 30, 1300–1345 LT time period for the Simulated Bomb Threat Drill occurred when winds were at their “high velocities” and the dominant WD was westerly. The Solar Radiation minimum and maximum values were 134 and 1016 W/m<sup>2</sup>, respectively. These extreme values over such a short period indicate an intermittent cloud deck obscuring the sun. The temperature variation between the windward and leeside of the building was not significant, implying that any shadowing effects by the local morphology were minimal.

The acceleration over (Velocity Acceleration) and between (Canyon Flow) buildings were both present with respect to the SW fetch tower data. On the leeside of the building, the NE and SE towers both showed relatively strong westerly winds at 10-m AGL that distinctly decreased in velocity as they approach the ground. A cavity flow/flow reversal pattern was expected on the leeside of the building. At 2.5-m AGL, the orientations of the NE and SE tower winds indicated direction reversal. For the SE tower, the light and consequently variable winds favored a southeasterly orientation at the low level [figure 8(a) and (b)]. The lower level NE tower winds were a bit more scattered with a bimodal collection of southeasterly and northeasterly directions [figure 9(a) and (b)]. Putting these coincident observations together, there is an implied subtle convergence near the leeside-center of the building. The significance of this pattern will be discussed further in the Drill Observations section.

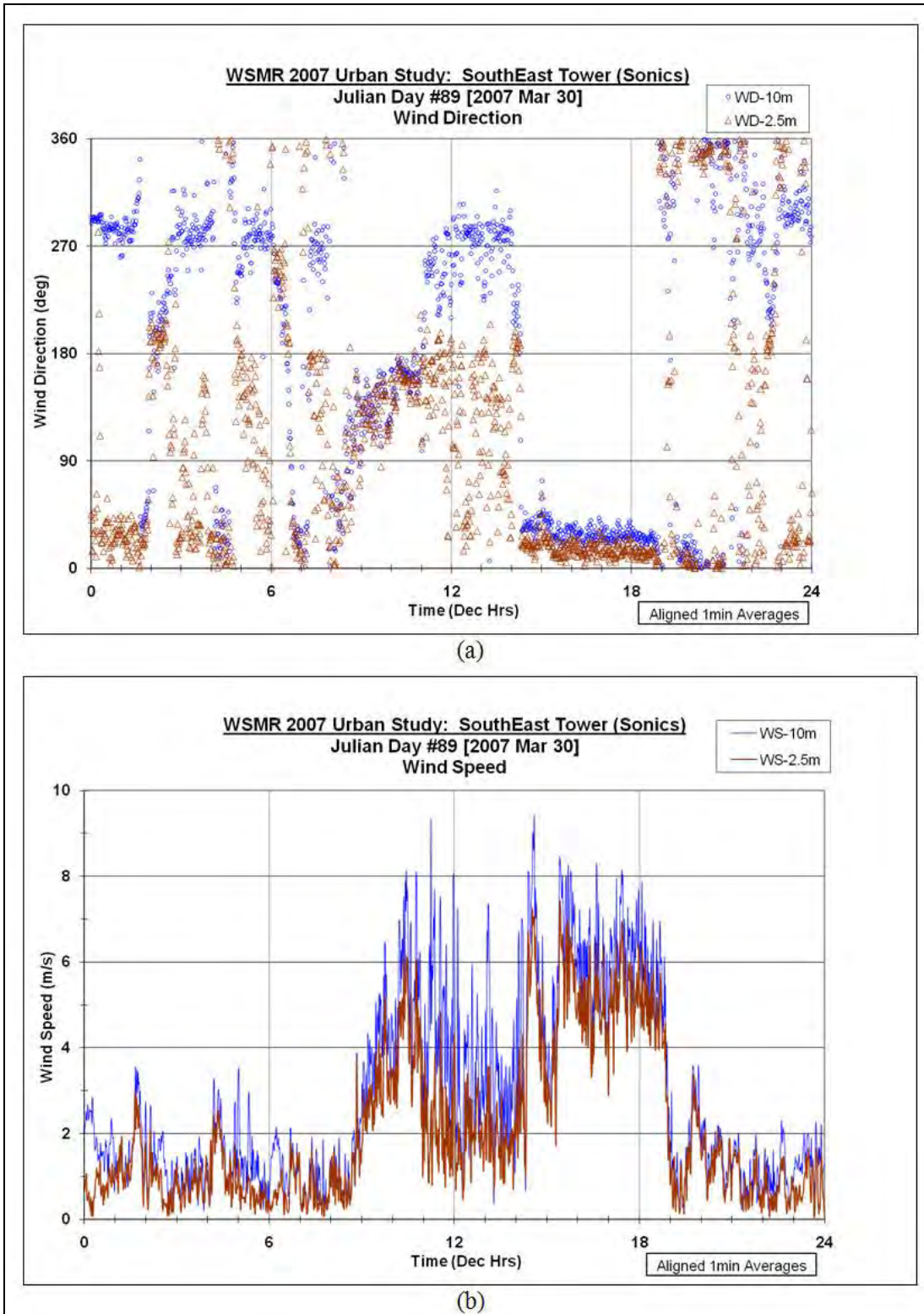


Figure 8. Simulated Bomb Threat Drill Day (sonic data)—Southeast tower: (a) SE WD data; (b) SE WS data.



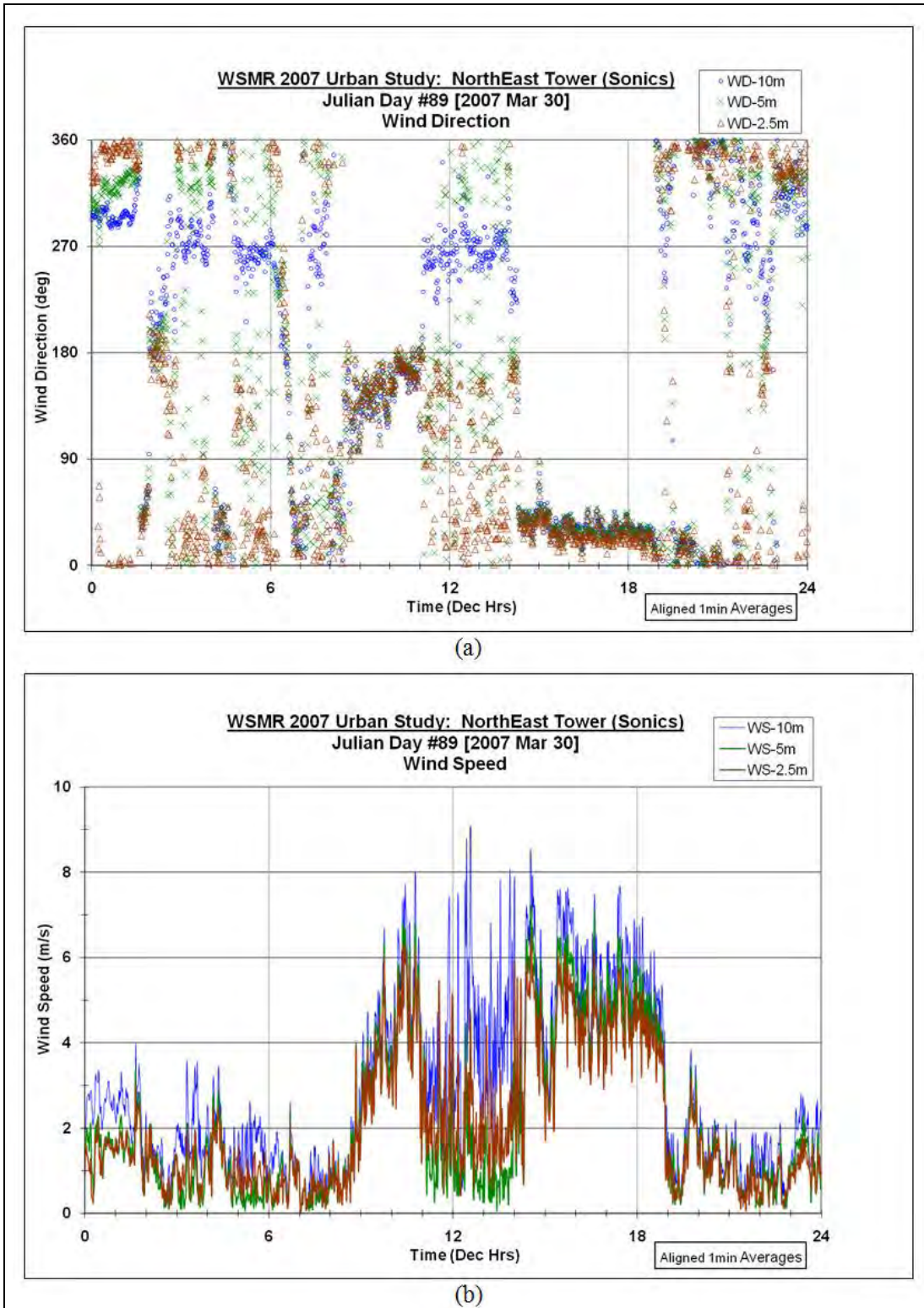


Figure 9. Simulated Bomb Threat Drill Day (sonic data)–NE tower; (a) NE WD data; (b) NE WS data.

#### **4.4 Safety Drill Observations**

The Simulated Bomb Threat Drill did not include an airborne element. However, for discussion purposes, a simulated explosion is added. The following observations begin after the initial burst has rained out its first gravity and momentum driven debris, leaving a residue dust cloud of air-carried substances yet to find their landing locations.

This addition to the drill placed the simulation-bomb on the north side of the building. The fixed NE rally location for personnel would be within the footprint of the initial burst. This obviously would not be the best choice for the rally point in this scenario. Presuming the personnel survived the initial blast and downpour of projectiles and the secondary flow of fumes and debris followed the local airflow patterns, the initial direction of the airborne elements would have been from west to east, adding yet another round of potential discomfort to the assembled personnel.

Even without a computer model of the explosion simulation, the fixed assembling location and the atmospheric conditions for this drill indicate a serious need for alternate gathering points. As a first suggestion, one might consider moving personnel upwind to a location determined by the atmospheric situation (to the west for this simulation) and for added protection, behind some protection. Gathering points in response to any potential explosion would have to be quite some distance away.

---

### **5. Simulated Airborne Chemical Release Drill**

---

The Simulated Airborne Chemical Release Drill activities utilized an airborne threat similar to those reported in the 2007 Iraqi war zones (*Toxic gas latest insurgent weapon in Iraq*, CNN Web page, 2007). In the next section, the human response to this drill will be described.

#### **5.1 Simulated Airborne Chemical Release Drill Activities**

The Simulated Airborne Chemical Release Drill occurred on Monday, 2007 April 02. At 0952 MT, the Disaster Response PI informed the work force of a simulated, potential cause for a SIP later in the day. That is, a tractor trailer carrying chlorine gas was to be escorted through the facility gate later that morning or in the early afternoon. At 1305, the PI provided the workforce with the simulated airborne chemical release scenario:

—...the tractor trailer, which was being escorted from ...gate to ...gate, overturned spilling 200 gallons of chlorine gas at ... cross streets. HAZMAT (hazardous materials) crews responded to the scene. Exposure to chlorine gas causes serious health hazards - burning of eyes and nose, nausea, choking, suffocation, excessive fluid in the lungs and death.”



The workforce was then instructed to report to their SIP locations. A slide was manually installed on the subject building's lobby display, informing occupants of the drill status and requirements.

All persons in the subject building quickly reported to the SIP location. A verbal description of how to seal the vents, windows and doors, and a sample of the sealing material was provided by the PI. Informal comments by the workforce offered several suggestions and lessons learned for subsequent drills/SIP events. The drill concluded at 1320 MT (Vaucher, 2007c).<sup>††</sup>

## **5.2 General Atmospheric Conditions on the Simulated Airborne Chemical Release Drill Day**

The atmospheric condition for 2007 April 02 (JD #92) was sunny/clear. A fairly flat dry zonal flow was present over NM, resulting in warm, relatively dry weather.

Two dominant wind patterns occurred over this 24-h period. From 0000 to 0955 MT, there were low velocity winds (Calm to Light Breeze) from the northwest. From 0956 to 2359 MT, high velocity winds (Light Air to Strong Breeze) flowed from the west.

During the low velocity scenario, the average WS was  $1.2 (\pm 0.5)$  m/s at 10 AGL (SW tower). There was a sub-period of 2 h after sunrise (0730–0930 MT), during which the WD shifted to southeasterly winds. The low velocity pattern persisted, despite the orientation change. Taking the 10-m AGL winds from the SE tower, the average velocity for this sub-period was still  $1.2 (\pm 0.5)$  m/s.

The high velocity wind scenario ran from 0956 to 2359 LT. The persistent WD for this second pattern was westerly. As figure 10 (a) and (b) shows, within this westerly orientation was a gradual shift from the southwesterly side of west, to a slightly west-northwesterly orientation. The average WS for the high velocity pattern was  $6.2 (\pm 2.4)$  m/s at 10 AGL (SW tower). The maximum WS recorded by the fetch tower (SW tower) for this day was 12.0 m/s at 1642 LT. The maximum WS recorded over the entire subject area was “Near Gale” and came from the Roof tower (6 m ArL): 15.1 m/s at 1626 LT.

---

<sup>††</sup> Notes taken by W07US Test Director-Vaucher.

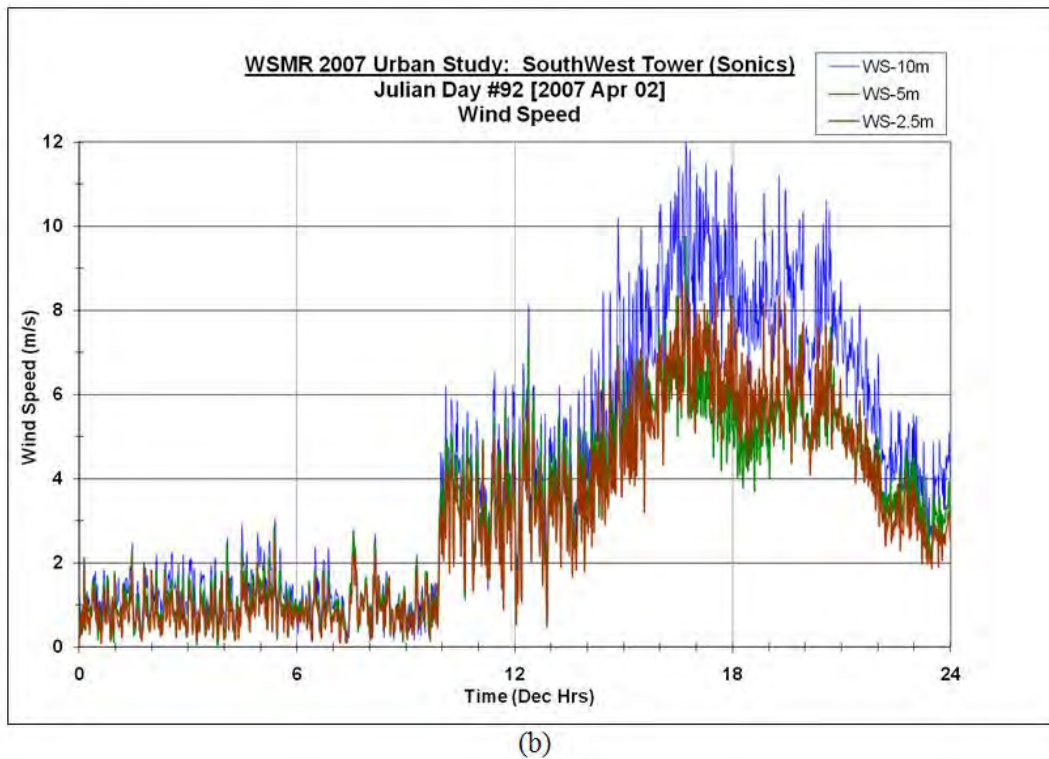
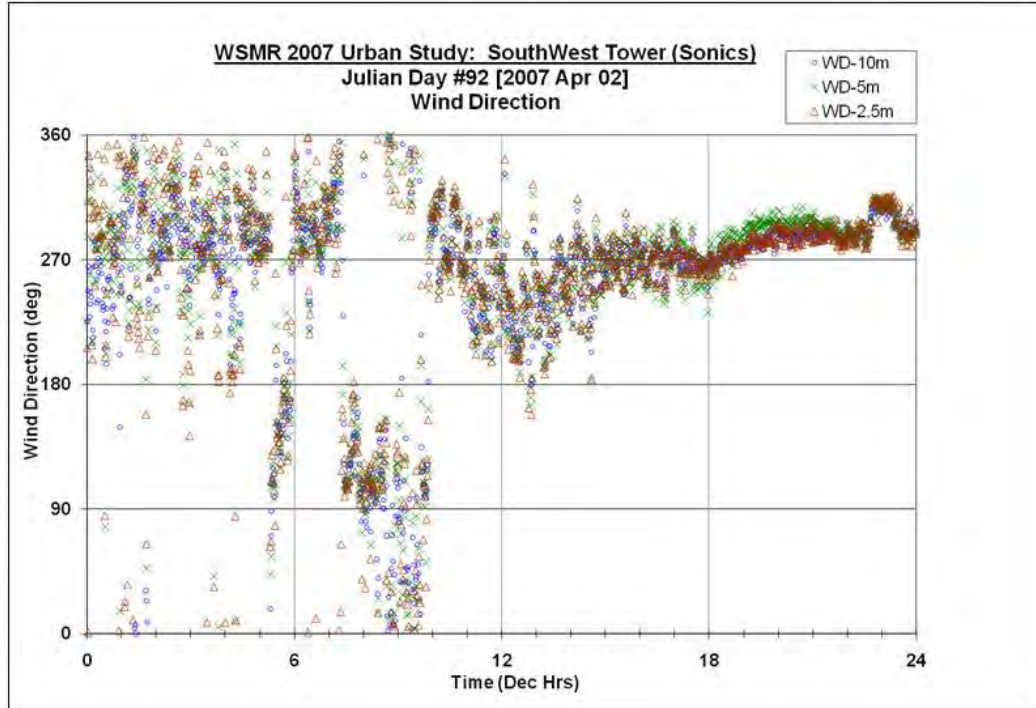


Figure 10. Simulated Airborne Chemical Release Drill Day (sonic data)–Southwest tower: (a) SW WD; (b) SW WS.

This drill day was the third of a three-day warming cycle. The average temperature (10-m AGL-SW tower) was 21.2 °C. The day's minimum temperature of 10.6 °C was reported in both the North tower (10-m AGL) at 0547 LT and SW tower (2.5-m AGL) at 0608 LT. The highest temperature for this date was 28.4 °C, which was reported in three locations. To help distinguish the thermal conditions, the thermal magnitudes are shown in table 8 prior to being numerically rounded:

Table 8. Maximum *W07US* temperatures for 2007 April 2.

Horizontal Location	Vertical Location	Pre-rounded 2007 April 2 Maximum Temperatures	LT
Roof tower	0.7-m ArL	28.41 °C	1352 h
North tower	2.5-m AGL	28.36 °C	1354 h
SW tower	2.5-m AGL	28.39 °C	1449 h

Aside: Before correlating the Roof and North tower temperature magnitudes, one needs to note that there was a vertical sampling height difference of about 8 m between these two samples. A cursory look at the coincident 1-min averaged roof WDs could imply a brief window of opportunity during which the heat of the roof might have been swept northward and into the North tower airspace. However, there were no North tower 10-m AGL temperature readings over the given time interval that would provide justification for this presumption. Any further investigation of this observation is beyond the scope of the current technical report.

RH on this date showed a typical cycle of moist morning air (31%) around sunrise, lowering by noon as the temperature rose and remaining low for the remainder of the day. The average RH for this day was about 15%.

### 5.3 Measured Atmospheric Data during the Simulated Airborne Chemical Release Drill

The April 2 Simulated Airborne Chemical Release Drill occurred between 1305 and 1320 MT, when winds were at their “high velocities” and the dominant WD was on the southwestern side of westerly. Consequently, the SW tower was used to characterize the atmosphere during this Drill. The event occurred 45 min after the day's maximum solar radiation (999 W/m<sup>2</sup>) and ~1.6 h before the temperature maximum (28.4 °C) for the day. During the drill, the average temperature was 26.2 (±0.3) °C (10-m AGL, SW tower) and the average RH was 9 (±0.3)%.

The southwesterly airflow sampled between 2.5 and 10-m AGL oscillated between 188 and 260 degrees, averaging ~233 degrees. The average 10-m AGL velocity was 4.3 (±1.0) m/s. Table 9 shows the average vertical wind profile for the 16-min drill period.

Table 9. Simulated Airborne Chemical Release Drill–2007 April 02.

SW Tower				
Simulated Airborne Chemical Release Drill 2007 Apr 2	Averaged WS (m/s)	±Std Dev WS (m/s)	Averaged WD (deg)	±Std Dev WD (deg)
1305–1320 LT				
10 m–sonic# 1360	4.3	1.0	231	18
5 m–sonic# 1358	3.9	0.9	233	21
2.5 m–sonic# 1359	3.5	0.8	234	23

The average airflow over the subject building showed the expected slight acceleration, with respect to the southwesterly fetch tower data. On the leeward side of the building, the NE and SE towers both showed relatively strong westerly winds at 10-m AGL. Near the ground, the SE tower showed a slower velocity; however the cavity flow feature appeared to be erased by a southerly flow [see figure 11 (a) and (b)]. The NE tower also reported southerly flow dominance, along with no distinguishing velocity changes between the upper and lower data sampled. The significance of this pattern is expounded upon in the Safety Drill Observations section.

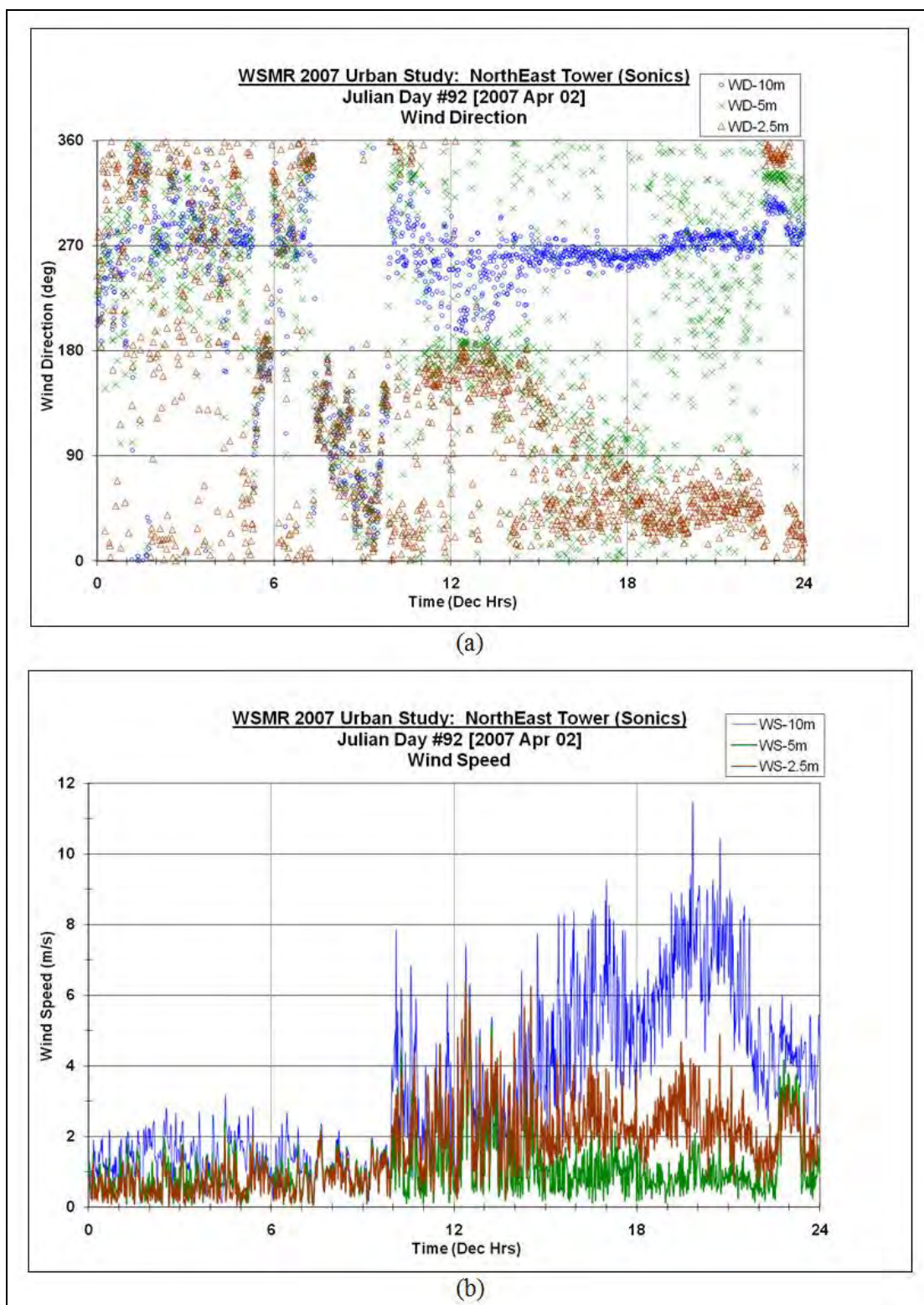


Figure 11. Simulated Airborne Chemical Release Drill Day (sonic data)–Northeast tower: (a) NE WD data; (b) NE WS data.

## 5.4 Model Simulations

The 16-minute, Simulated Airborne Chemical Release Drill was re-created using two models. The first model was the diagnostic 3DWF Model, which mapped a three dimensional airflow pattern around the subject buildings, based on the measured vertical wind profile data sampled on the SW tower. Using a 1-minute average, 16 overview slices cut at 2.5-m AGL (just above a tall human head) and vertical slices midway through the subject building ( $y=130\text{m}$ ) were created; one image for each minute of the drill.

The second model used to simulate the chemical release drill was the NOAA/EPA dispersion model, ALOHA. Figure 12 summarizes the input scenario. The chemical release was 200 gallons (gal) (2318 pounds [lb]) of liquid chlorine released in 1 min. The Heavy Gas Model was run. Three threat zones based on standard level of concern (LOC) gradients were mapped, each representing a threshold of hazard to the human body. For this case, concentrations of  $<0.5$  parts per million (ppm) mapped the area where health effects were not disabling and were reversible upon cessation of exposure (Acute Exposure Guideline Level [AEGL]-1, yellow line). The irreversible, long lasting adverse effects leading to an impaired ability to escape were contained in areas  $>0.5$  ppm, and  $<2$  ppm concentrations (AEGL-2, orange line). Concentrations  $>20$  ppm represented health effects that were life-threatening or the cause of death (AEGL-3, red line). ALOHA also provided an uncertainty line around the longest threat zone. This perimeter line represented the region between which the gas cloud was expected to remain for about 95% of the time. Note that in ALOHA, the 60-min AEGL exposure limits are the default toxic LOC. In other words, the toxic gradients are considered valid for a maximum of 60 min.

In appendix D, the 16 one-minute sequences of both wind flow and simulated chemical release footprints are presented. When animated, the wind flow model cycles through a southwesterly orientation where the cavity flow extends about 150–160-m east of the subject building, to a southerly orientation, which skews the cavity flow northeastward, reducing the horizontal footprint to less than 120-m east of the building. At the end of the drill period, the southwesterly fetch flow resumes, bringing back the original cavity flow.

Focusing on the 16-min of plume footprints, only 2-min (at the start and end of the drill) placed the rally point in a safe area. For the remaining 13 min, the rally point was either within the 95% uncertainty curve or in the lethal zone (AEGL-3). When the winds became southerly, the lethal zone overlapped the rally point. Once the southwesterly winds returned, the chemical concentration reduced to survivable dosages.



<b>SITE DATA:</b>	
Location: WHITE SANDS MISSILE RANGE, NEW MEXICO	
Building Air Exchanges Per Hour: 0.47 (unsheltered double storied)	
Time: April 2, 2007 1305 hours MDT (user specified)	
<b>CHEMICAL DATA:</b>	
Chemical Name: CHLORINE	Molecular Weight: 70.91 g/mol
AEGL-1(60 min): 0.5 ppm	AEGL-2(60 min): 2 ppm
IDLH: 10 ppm	AEGL-3(60 min): 20 ppm
Ambient Boiling Point: -35.4° F	
Vapor Pressure at Ambient Temperature: greater than 1 atm	
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%	
<b>ATMOSPHERIC DATA:</b>	
Wind: 5.23 meters/second from 218° true at 10 meters	
Ground Roughness: urban or forest	Cloud Cover: 0 tenths
Air Temperature: 26.6° C	Stability Class: C
No Inversion Height	Relative Humidity: 9%
<b>SOURCE STRENGTH:</b>	
Direct Source: 200 gallons	Source Height: 0
Source State: Liquid	
Source Temperature: equal to ambient	
Release Duration: 1 minute	
Release Rate: 38.6 pounds/sec	
Total Amount Released: 2,318 pounds	
Note: This chemical may flash boil and/or result in two phase flow.	
<b>THREAT ZONE:</b>	
Model Run: Heavy Gas	
Red : 1.4 miles --- (20 ppm = AEGL-3(60 min))	
Orange: 3.1 miles --- (2 ppm = AEGL-2(60 min))	
Yellow: 5.0 miles --- (0.5 ppm = AEGL-1(60 min))	

Figure 12. Simulated airborne chemical release specifications.

## 5.5 Safety Drill Observations

Four observations were noted after analyzing the previously described simulated airborne chemical release drill and coincident atmospheric data:

(A) The Chlorine released at —...ross streets” placed the chemical hazard south and east of the subject building. Based on the *2008 Emergency Response Guidebook* (U.S. Dept of Transportation, 2008), if the initial chlorine release estimate was considered a —Small Spill,” then the subject building would have been just on the edge of the required 200-ft isolation area. Being daytime, the area for protection was 0.3 miles, which included the subject building. If this event was considered a —Large Spill,” the first area isolated would have included the subject building.

To expect building occupants to know the above safety specifications at the time of the spill would be unreasonable. First responders with access to the chemical threat details and this required guidebook, however, could provide instructions to the workforce. They would need time to gather the needed information, which prompts the question: Would their assessment still be relevant when it became available?

Converting the preceding into observations:

1. There is a need for efficiently gathering information regarding the airborne hazard and assessing its impact on human life.
2. There is a need for timely information to be effectively communicated to the various impacted personnel.
3. Information communicated needs to still be relevant to the current dynamic situation.

(B) Buildings with positive pressure (constant outward flowing air) provide the best protection for building occupants faced with an external airborne threat. As part of the drill, an alternate strategy of sealing the SIP room from outside fumes was utilized. Was this a good response?

The prevailing winds during the drill were southwesterly. However, there was enough variation in the direction to cause a southerly flow to run along the leeside of the building. Reviewing the four-dimensional SE and NE tower wind data, this channeled southerly flow negated the typical leeside cavity flow feature. The lack of decreased velocities near the ground (an attribute of the cavity flow) served as a positive element in preventing the chemical from loitering. However, any outside building openings on the leeside would have encountered the traveling toxic fumes. In other words, a leeside SIP room window not sealed properly would have brought the airborne threat into the place of refuge. In contrast, a SIP room on the windward side of the building would have potentially reduced the risk.

(C) Once the personnel were secured, could a decision to evacuate the building been safely executed? A cautious “yes” is answered. With full knowledge of the near real-time wind flow patterns around the building and at the release point, a site commander could have used the windward exits to create a relatively passable route-of-retreat to safety. This option was not included in the drill, since neither the near real-time meteorological data, nor a release-site plume projection were available to the emergency response decision makers.

(D) Finally, if the decision had been made to evacuate the building, instead of SIP, would the rally point have been safe? The assembly point was NE of the office building. Using the *2008 Emergency Response Guidebook* analysis: within 200 ft of the building, a simulated chlorine spill was filling the air with its toxic plume. This assessment is re-enforced by the post-event wind field and plume model results, which showed periods where the atmospheric conditions caused the air/plume to be channeled from the south to the north. Consequently, if an uninformed evacuation decision was given, those persons exiting on the building leeside (east) would have been placed directly in line with the hazardous release. Cascading from such an evacuation order, innate self-preservation decisions would have scattered the vulnerable workforce, making the needed 100% accountability nearly impossible due to reasons cited earlier in the other drill observations. Without 100% accountability, identifying those persons still in the building would be very difficult. Fortunately, the original Test Plan called for the workforce



to SIP in response to the simulated threat, keeping personnel away from the very vulnerable NE rally location.

In summary, there were two possible responses for the airborne chemical release drill: evacuate or SIP. If the decision had been to evacuate to the NE rally point, the atmospheric conditions would have created a potential human disaster. If the decision to SIP was made, personnel might have been temporarily uncomfortable, but the hazardous chemical impact would have been much reduced.

What this drill demonstrates is a serious need for accessible, timely, relevant and user-friendly chemical and atmospheric information. In an emergency, decisions will be made by onsite personnel (individuals and managers), as well as the rescuers (trained first responders, site commanders, etc.). These are the persons who most need this timely and relevant situational awareness.

---

## **6. Assimilating Drill Observations**

---

This research was intended to calibrate the effectiveness of the 2007 ARL safety procedures, by analyzing coincident atmospheric measurements sampled during three disaster response drills. In these drills, the fixed rally point often put the workforce in a hazardous environment. Consequently, the study's first recommendation is to re-define the subject building's rally point. For airborne hazards, a general "rule of thumb" for finding a safe location is to go upwind of the hazardous release. Since studies have shown that winds in the immediate area of buildings are variable, determining the prevailing WD(s) for a building requires investigating the climatological records for the subject building's area, in general. From the climatologically-derived prevailing WD(s), upwind location(s) can be defined. In some cases, there are two or more dominant WDs; therefore, having more than one rally point pre-defined might improve the potential for survival. The difficulty will be in communicating which rally point is appropriate for a given situation. The subsequent sections address this concern.

---

## **7. A Valuable Lesson Learned**

---

Each drill, by definition, did not involve actual hazardous materials. But clearly, if the events were not drills, the workforce would have suffered ailments caused by un-informed decisions. The major lesson learned from this study was that decision makers need to be provided timely and relevant information regarding ongoing hazardous events. The "decision makers" referenced include: (1) all the onsite individuals who must make instantaneous, self-preservation decisions; (2) supervisors or building custodians who provide critical decisions as they advise the

workforce and manage the situation until trained medical or security personnel arrive; (3) emergency first responders, who initiate their decisions when they determine how to safely approach the incident, and continue their choices as they work within the dynamic hazardous environment. Note that emergency first responders include three areas: Security (law enforcers), Property (fire) and Human Safety (First Aid); and finally, (4) there are the incident commanders, who manage the larger situational countermeasures needed to quickly resolve the hazardous situation, and address all the public relations issues.

Throughout the many levels of decisions, the types of timely and relevant information required for disaster response decisions fall into three categories: (1) the type of hazard threatening human life, (2) the current hazardous condition within the environment, and (3) the best countermeasure/route-to-safety. To define the “hazard” type requires witnesses and/or chemical analysis sniffers, and any documentation regarding the hazardous source. The “current hazardous condition” requires a monitoring device that is able to continually characterize the environment. If the monitoring device was able to combine the projected hazard footprint with a visual representation of the current atmospheric conditions, the “best countermeasure/route-to-safety” would most likely become intuitive.

The final challenge would be how to get this relevant hazard information to the appropriate decision makers. With contemporary technology (such as the social networks) able to bring Web-type information to hand-held devices, one possible strategy would be to create an approved situational awareness resource that would automatically transmit this timely information to the mobilized workforce and rescue-professionals. Other possible solutions are presented in the “A Recommendation Implemented” section.

---

## 8. Summary

---

This research was intended to calibrate the effectiveness of the 2007 ARL safety procedures, by analyzing coincident atmospheric measurements sampled during three disaster response drills.

Every physical disaster is unique. Consequence Management Procedures and practical experience have produced safety training to help the workforce respond with as much potential for survival, as the emergency scenarios might yield. Executing controlled disaster response drills provide lessons learned that can be integrated into the training, resulting in improved safety procedures.

In 2007, ARL conducted a detailed urban atmospheric study called *W07US*, which investigated the airflow and stability around and above a single urban building. Included in the *W07US* were three disaster response drills. These drills consisted of a Simulated Fire/Smoke Release Drill, a Simulated Bomb Threat Drill, and a Simulated Airborne Chemical Release Drill. Due to visiting

dignitaries, the smoke release event was extracted from the Fire Drill, and executed on a separate day. The drill test site consisted of a subject building surrounded on three sides by buildings of similar size and materials. The fourth side included a sidewalk, a 4-row parking lot and a 4-lane street. Thermodynamic and dynamic meteorological data were acquired on all sides of the subject building, as well as, the roof. The data acquisition ran 24 hours per day/7 days a week (24/7) for about two weeks. Fifty-one sensors were used to sample Pressure, Temperature, RH, WS/WD and Solar Radiation. The thermodynamic data were documented in 1-min averages; dynamic data were sampled at 20 Hz. Note: For this study, the dynamic data were reduced to 1-min averages, aligned to the thermodynamic data.

The Fire Drill (2007 March 29) prompted the subject building to be evacuated to a rally point NE of the building. Preplanned actions by six volunteer role players triggered a search and rescue re-entry into the building. Four role players were successfully rescued from the building, and two role players manifested their ailments at the rally point. The thermodynamic conditions for the day were clear with temperatures between 4.3 and 18 °C, and low RH. Winds were a “Moderate Breeze” that decreased throughout the day to “Calm.” Two scenarios persisted: (1) for about 75% of the day, winds were from the west; (2) otherwise, they were from the south. During the drill, the winds were a southerly, light breeze (2.0 m/s). Had smoke been present during the drill, the NE rally point would have been challenged by the fumes for at least 27% of the time. The re-entry of the Safety and Fire Chief Officers on the northwest side of the building would also have been challenged by the smoke being pushed from south to north by the winds. The better rally point for the Fire Drill evacuation would have been upwind from the hazardous smoke plume. For this case, “upwind” would have been on the south side of the building. Applying this “upwind” assessment to the re-entry action, a safer entrance would have been made on the south side of the building.

The Simulated Bomb Threat (2007 March 30) did not include an explosion. However, since personnel were again evacuated to the NE rally point, this location was assessed for safety. Accepting the fact that surviving an initial blast at the rally point was perhaps wishful thinking, the analysis commenced with a second-level safety evaluation by looking at the subsequent airflow-driven debris (dust, gas leaks, etc.) that might have followed an explosion. The atmospheric conditions for this day were sunny and clear in the morning, and partly cloudy in the afternoon. The dynamic conditions began with 9 h of low wind velocities from the northwest quadrant. These conditions returned for the last 5 h of the day. In between the two periods, and during the drill, WSs increased significantly. During the drill, the dominant WD was westerly. Examining the building’s leeward measurements, the rally point was within the footprint of receiving added airborne hazards. A better post-blast rally point would have been upwind or west of the subject building. A better pre-blast rally point would have been upwind and several kilometers from the targeted site, depending on the bomb type and strength.

The Simulated Airborne Chemical Release Drill (2007 April 2) presented the most educational scenario for lessons learned. The airborne hazard was 200 gal of chlorine, accidentally released

SE of the subject building. By the Test Plan Drill requirement, the workforce was instructed to report to the SIP location. The other option, if this action had not been a pre-defined by the Test Plan, would have been to evacuate the building to the NE rally point.

The atmospheric conditions for the Simulated Airborne Chemical Release Drill day were sunny and clear. The dominant wind pattern for the first almost 10 h of the day was ~~“Calm”~~ to ~~“Light Breeze”~~ winds, and primarily from the northwest. From about 1000 MT through the day’s end, high velocity winds reaching ~~“near Gale”~~ conditions were from the west. The drill was executed during this latter period.

Atmospheric conditions during the Simulated Airborne Chemical Release period were clear, with an averaged-temperature of 26.2 °C and an averaged-RH of 9%. Winds were southwesterly at about 4 m/s. The building flow was expected to produce a leeside cavity flow; however, the oscillation of WDs over the drill time period created a leeside channeling effect along the eastern side of the building. The Test Plan requirement to SIP was correct, as per the coincident atmospheric conditions. Had the Test Plan called for an evacuation to the NE rally point, the Post-Drill analysis showed that personnel would have encountered direct exposure to the airborne chemicals. Safety guidelines applicable to this incident scenario and post-incident atmospheric modeling re-enforced these results.

Each drill, by definition, did not involve hazardous materials. But clearly, if the simulated incidents were not drills, the workforce could have suffered ailments caused by un-informed decisions. The major lesson learned from this study was that decision makers need to be provided timely and relevant information regarding an ongoing hazardous incident. Decision makers include the incident commander, emergency first responders, supervisors or building custodians who advise the workforce, and individuals who must make instantaneous self-preservation decisions.

The recommended ~~“timely and relevant information required”~~ falls into three categories: (1) the type of hazard threatening human life, (2) the current hazardous condition within the environment, and (3) the best countermeasure/route-to-safety. To define the ~~“hazard type”~~ requires witnesses, chemical analysis sniffers and hazard source documentation. Assessing the ~~“current hazard condition”~~ would require a monitoring device that was able to continually characterize the environment. If the monitoring device combined the projected hazard footprint with a visual representation of current environmental conditions, the ~~“best countermeasure/route-to-safety”~~ would most likely become intuitive.

Communicating the relevant hazard information to the appropriate decision makers, in a timely manner, is non-trivial. Contemporary technology is able to bring Web-type information to hand-held devices; therefore, one possible solution would be to create an approved situational awareness resource that would automatically transmit this timely information to the mobilized workforce and rescue professionals. One of ARL’s responses to this lesson learned is presented in the next section.

---

## 9. L-REAC™ System, an Implemented Recommendation

---

During a toxic airborne hazard incident, how can one define and communicate current atmospheric conditions in a timely manner?

The concept for an atmospheric monitoring system designed to provide 24/7 airflow maps and, when applicable, mapped hazardous plume footprints, to authorized end users, began at the conclusion of the *W07US* field study. This system became known as the “Local-Rapid Evaluation of Atmospheric Conditions (L-REAC™) System”. The L-REAC™ System “Proof of Concept” design consisted of three major Modules, each focused on providing timely and relevant information to office building occupants. The Sensor Module consisted of standard meteorological sensors that continually (24/7) ingested data from a strategically-placed location, which complied with scientific, as well as, security and safety requirements. The Model Module perpetually processed this continual data feed with a diagnostic three-dimensional wind flow model, producing a detailed map of airflow around the subject building within a minute of the data acquisition. When an incident or drill occurred, the End User Display (EUD) Module supplemented the L-REAC™ output with a plume model graphic projecting a chemical plume overlay onto a separate common map. The plume model setup was initiated by a user, who selected the appropriate chemical specifications. The plume model automatically linked to the perpetual meteorological data being ingested, for subsequent plume calculations. The L-REAC™ processed and fed these outputs to a public display within the subject building and a SIP location, within 1 to 2 min of the data ingest. (Vaucher et al., 2009)

The L-REAC™ System-Prototype expanded the original design to include the ingesting of local and regional (mesonet) meteorological data. The airflow model was expanded to include a cantonment (town/small city) area, and the building scale AOI. The final mapped products were accessible by the entire workforce impacted, authorized public users and SIP locations. (Vaucher et al., 2010).

At the time of this writing, the L-REAC™ System was transformed into an operational system. The improved data ingest included the dedicated local L-REAC™ System meteorological data, as well as, —live cantonment and regional (mesonet) data resources. The model module consisted of automated 24/7 wind field model runs with the option of three different resolutions/scales: building, cantonment, and regional. The efficient (less than 1 min) plume model output, continued to supplement the wind field outputs. The EUD output presented the end-user with two visualizations of the wind field and plume footprint mapped onto a satellite image background. In one image, the user could easily zoom in/out of a given AOI. With the other, a more detailed building scale of the wind field aligned next to an equally proportioned map of the plume footprint. The logistics for communicating directly to hand-held devices was proven as

feasible. The entire System had been subjected to several simulation Exercises, as well as a real world operational event involving the WSMR/Fire Dept, WSMR/Installation Operational Centers (IOC) and NM Bureau of Land Management. And finally, the L-REAC™ System had undergone a detailed evaluation for design improvements by professionals from the IOC, Emergency Operations Center and Fire Department (Vaucher et al., 2011). For more information, contact the author.

---

## 10. Mission Accomplished

---

One of the most rewarding features of research is being able to see a positive impact on humanity within the researcher's lifetime. The research objective that began this investigation was ~~to~~ improve situational awareness for both soldiers and civilians facing airborne hazards." After the *W07US* Field Study and Disaster Response Drills were executed, preliminary results were assembled and later formalized into technical reports, such as this one. Two significant products have come from this work:

- (1) Safety Standard Operating Procedure (SOP) Updated: The results from investigating the coincident disaster response drills and atmospheric conditions were communicated to the subject building safety personnel. In response, the workforce who participated in the drill activities now has multiple rally points, which satisfy pre-defined safety regulations and are in keeping with the ~~upwind~~" safety concept. They also have access to timely and relevant atmospheric information through the design and development of the second significant product, the L-REAC™ System.
- (2) The L-REAC™ System: Using the *W07US* measurements and analysis, the L-REAC™ System was designed, constructed and tested as a decision maker's tool for real-world airborne released hazards. At the time of this writing, this system was able to provide automated, near real-time input for decision makers that were (1) resident to the threatened building, (2) approaching and dealing with the airborne hazard, and (3) managing top level demands of a disaster response from an IOC.

The L-REAC™ System is in the process of advancing its components to keep up with the current technology and decision maker feedback. In this process, the research continues to draw upon the quantitative urban field measurements, urban modeling, data analyses and practical experience gained from the original and subsequent disaster response drills. As we do, better-quality decision aid tools will continue to be designed and developed, creating improved situational awareness and the potential for more life saving decisions.

---

## 11. References

---

- ALOHA User's Manual*, The CAMEO Software System, EPA/NOAA, February 2007.
- CNN Web page, *Toxic gas latest insurgent weapon in Iraq*,  
<http://www.cnn.com/2007/WORLD/meast/02/22/iraq.main/index.html> (accessed 2007 February 22).
- Met Office, Beaufort Wind Force Scale*,  
<http://www.metoffice.gov.uk/weather/marine/guide/beaufortscale.html> (last accessed: 2010 October 14).
- Multiservice Tactics, Techniques, and Procedures for Chemical, Biological, Radiological, and Nuclear consequence Management Operations*, FM3-11.21, MCRP 3-37.2C, NTTP 3-11.24, AFTTP(I) 3-2.37, Apr 2008.
- Snyder, W.; Lawson, Jr., R. *Wind-Tunnel Measurements of Flow Fields in the Vicinity of Buildings*, 8<sup>th</sup> Conference on Applied Air Pollution Meteorology with A&WMA, Nashville, TN, AMS, Boston, pp 244-250, January 1994.
- U.S. Department of Transportation, *2008 Emergency Response Guidebook*, U.S. Dept of Transportation - Pipeline and Hazardous Materials Safety Administration, 2008.
- Vaucher, G. T. *Urban-Small Building Complex Environment: Comparing Stable Patterns from Two Similar Urban Field Studies, Volume AS-1*; ARL-TR-4456; U.S. Army Research Laboratory: White Sands Missile Range, NM, September 2007a.
- Vaucher, G. T. *Urban-Small Building Complex Environment: W07US Stability Analysis and Inter-Study Comparison, Volume AS-2*; ARL-TR-4452; U.S. Army Research Laboratory: White Sands Missile Range, NM, May 2008d.
- Vaucher, G.T. *Urban-Small Building Complex Environment: W07US Stability Analysis and Inter-Study Comparison, Volume AS-3*; ARL-TR-4954; U.S. Army Research Laboratory: White Sands Missile Range, NM, September 2009.
- Vaucher, G. T. *W07: 2007 Mar 28 - A successful Urban Study Smoke Release*. Personal communication with Donald Hooch et al., March 28, 2007e.
- Vaucher, G. T. *W07: Documentation of Successful Simulated Bomb Threat Drill (2007 Mar 30)*. Personal communication with Donald Hooch and Joseph Trammel, April 11, 2007c.
- Vaucher, G. T. *W07: Documentation of the Successful ARL Risk Management Drill (2007 Mar 29)*. Personal communication with Donald Hooch et al., March 30, 2007b.

- Vaucher, G. T. *W07: SIP drill (2007 Apr 2) Documentation*. Personal communication with Donald Hoock et al., April 11, 2007d.
- Vaucher, G. T. *W07US Test Plan –WSMR 2007 Urban Study: Flow and Stability Around a Single Building*”; U.S. Army Research Laboratory: White Sands Missile Range, NM, December 11, 2006.
- Vaucher, G. T.; Brice, B.; Luces, S.; O’Brien, S. *Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) System, Design and Development, Volume 3 (“Operational L-REAC™ System”)*; ARL-TR-5727; U.S. Army Research Laboratory: White Sands Missile Range, NM, September 2011.
- Vaucher, G. T.; Brice, R.; D’Arcy, S.; Bustillos, M.; Cionco, R. *White Sands Missile Range 2007 Urban Study: Data Processing - Volume DP-1 (Sonic Calibration)*; ARL-TR-4439; U.S. Army Research Laboratory: White Sands Missile Range, NM, September 2008a.
- Vaucher, G. T.; Bustillos, M. *White Sands Missile Range 2007 Urban Study: Data Processing - Volume DP-3 (Airflow Qualitative Assessment)*; ARL-TR-4441; U.S. Army Research Laboratory: White Sands Missile Range, NM, May 2008c.
- Vaucher, G. T.; Bustillos, M.; D’Arcy, S.; Brice, R.; Cionco, R.; Chamberlain, F.; Trammel, J.; Luces, S.; Padilla, R.; Yarbrough, J. *White Sands Missile Range 2007 Urban Study: Flow and Stability Around a Single Building, Volume 1: Field Study Overview*; ARL-TR-4255; U.S. Army Research Laboratory: White Sands Missile Range, NM, September 2007.
- Vaucher, G. T.; D’Arcy, S.; Brice, R.; Bustillos, M.; Cionco, R. *White Sands Missile Range 2007 Urban Study: Data Processing - Volume DP-2 (Main Dataset)*; ARL-TR-4440; U.S. Army Research Laboratory: White Sands Missile Range, NM, September 2008b.
- Vaucher, G. T.; Luces, S.; O’Brien, S.; Brice, B. *Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) System, Design and Development, Volume 2 (“Prototype”)*; ARL-TR-5332; U.S. Army Research Laboratory: White Sands Missile Range, NM, September 2010.
- Vaucher, G. T.; Luces, S.; O’Brien, S.; Brice, B.; Bustillos, M.; D’Arcy, S. *Local-Rapid Evaluation of Atmospheric Conditions (L-REAC) System, Design and Development, Volume 1 (“Proof of Concept”)*; ARL-TR-4958; U.S. Army Research Laboratory: White Sands Missile Range, NM, September 2009.
- Wang, Y.; Williamson, C.; Garvey, D.; Chang, S.; Cogan, J. Application of a multigrid method to a mass consistent diagnostic wind model. *J App Meteorol* **2005**, *44*, 1078–1089.



---

## Appendix A. Smoke Release Drill Summary

---

The smoke release was conducted independent of the Fire Drill. The following paragraphs summarize the Smoke Release event:

The Smoke Release Drill took place on 2007 Mar 28 around the same subject building as the Fire Drill. The event began around a conference table, where the WSMR Fire Department Chief briefed the *W07US* participants regarding the smoke release device and requirements. The *W07US* Test Director then spelled out the intended smoke release choreography for the afternoon drill.

Smoke release operator was the WSMR Fire Department Chief. He used three generators with banana oil. The smoke was white/gray in color. The winds were strong and generally from the western quadrants.

Between 1330–1600 Mountain Daylight Time (MDT), eight separate smoke releases were executed. Smoke was released at the heights of 1–1.5-m AGL. Cases 1–6 were issued from the ground at various points SW and south of the building. Cases 7–8 were both issued from the roof (west and east sides).

Observers with notepads were located on the ground (three observers) and on the roof (one observer). The observer locations included: the smoke source, south of the release, north/leeside of the building, and on the roof. A hired camera crew filmed and photographed the results. Various other observers joined us throughout the event. A common time stamp unified the observations and the data.

The final witnessed and filmed results will be presented in an independent publication. However, in summary, observers reported several unexpected and expected four-dimensional patterns (u, v, w, time). Lessons learned from this exercise included several logistical points such as power requirements, and the level and intensity of smoke release.

Note: The arrangements for this event were made possible through the efforts of the ARL Risk Management Officer (Vaucher, 2007d).<sup>‡‡</sup>

---

<sup>‡‡</sup> Notes taken by *W07US* Test Director-Vaucher.

INTENTIONALLY LEFT BLANK.

---

## Appendix B. *W07US* Thermodynamic Data, 2007 March 28–April 2 (JD# 87-92)

---

This appendix displays the *W07US* thermodynamic data by tower, for JD #87-92 (2009 March 28–April 2). This time period includes the Smoke Release Drill, and all three *W07US* disaster response drills. The 1-min averaged data were sampled from the SW, Roof, NE, South, and North towers. The order of meteorological variables within each tower group is Solar Radiation, Pressure, Temperature, Relative Humidity, WS and WD. A table of statistics for each drill day and drill event completes the tower data display group. These statistics were calculated using just the Thermodynamic data (Campbell dataset).

Note that these wind measurements were sampled at 5-m AGL, except on the roof. Each day was distinguished with a grid line at the start and end of the 24-h cycle. The sampling locations AGL are summarized in table B-1.

The roof sensor locations were unique: Net solar radiation (2-m ArL), two Temperature T107s (0.7 and 6-m ArL) and WS/WD (6-m ArL). No pressure sensor was installed on the roof; therefore, the Roof Tripod's Table of Statistics has left the "Pressure" (for pressure) column blank.

Table B-1. Vertical distribution of thermodynamic data sampled from the *W07US* towers installed on the ground level only.

Variable	Sensor	Manufacturer	Model	Location*	Units
Pressure	Barometer	Vaisala	PTB-101B	1-m AGL	Millibars
Temperature	Thermometer	Campbell	T107	10-m AGL	Celsius
Temperature/RH	Thermometer/ Hygrometer	Vaisala	HMP45AC	2-m AGL	Celsius/ Percent
WS and WD	Wind monitor	RM Young	05103	5-m AGL	Meter/second and degrees
Solar radiation	Pyranometer	Kipp/Zonen	CM3	2-m AGL	Watts/meter <sup>2</sup>
Net solar radiation	Net radiometer	Kipp/Zonen	NR-LITE	2-m AGL	Watts/meter <sup>2</sup>

For Winds sampled at 10-, 5- and 2.5-m AGL, see appendix C (*W07US* Dynamic Data).

## B-1 SW Tower

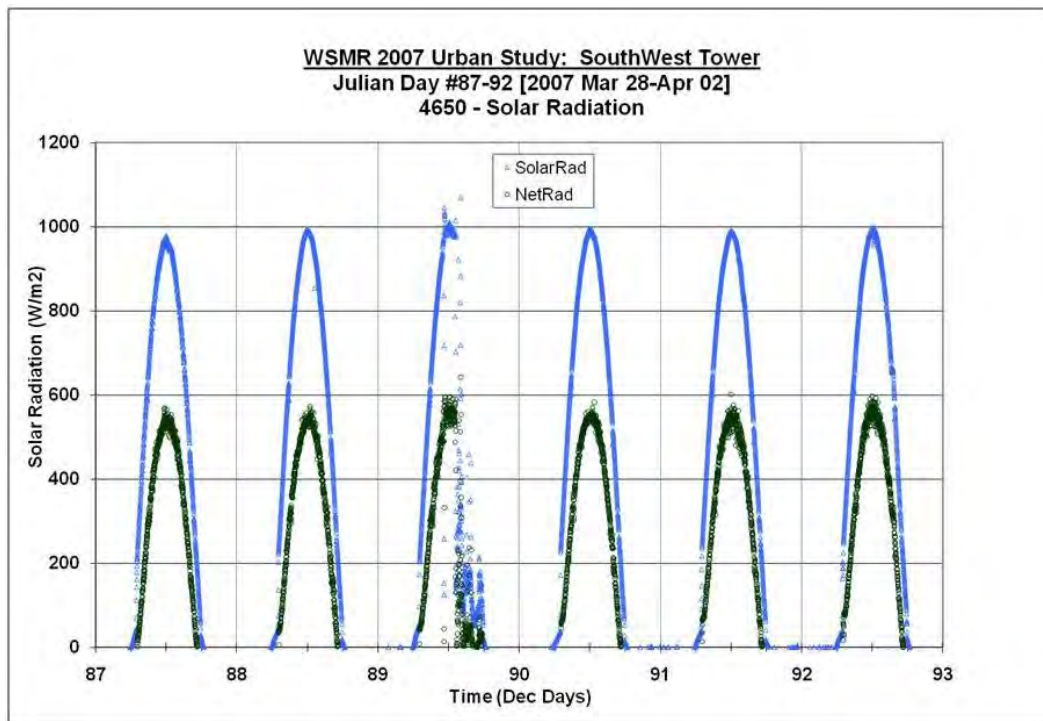


Figure B-1. SW tower: Solar radiation.

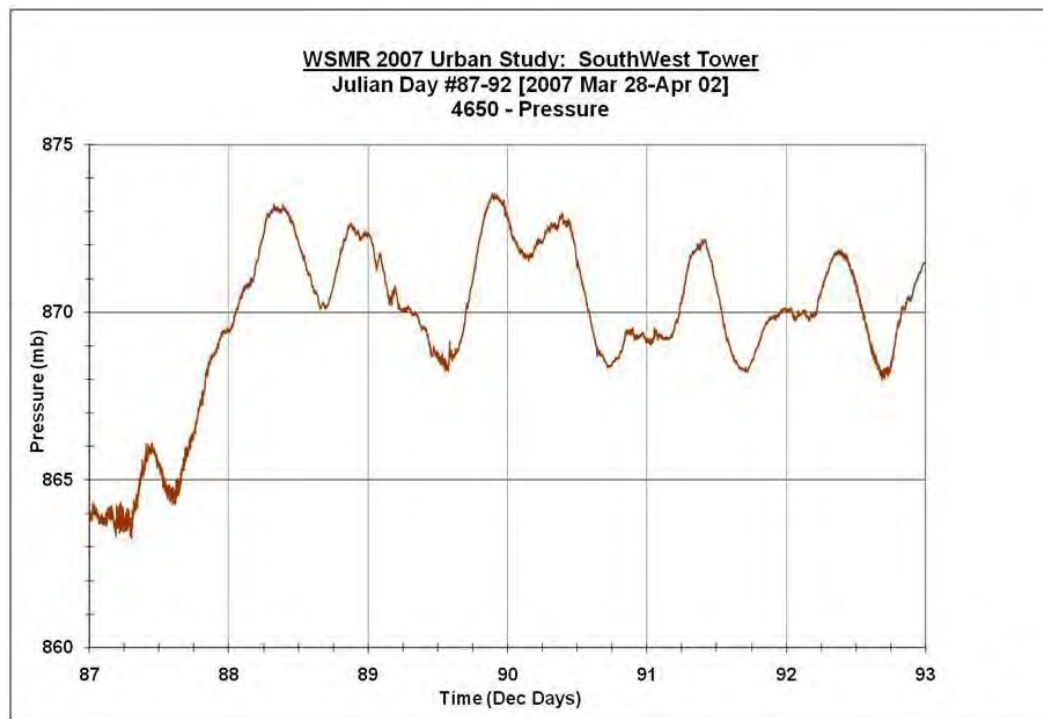


Figure B-2. SW tower: Pressure.

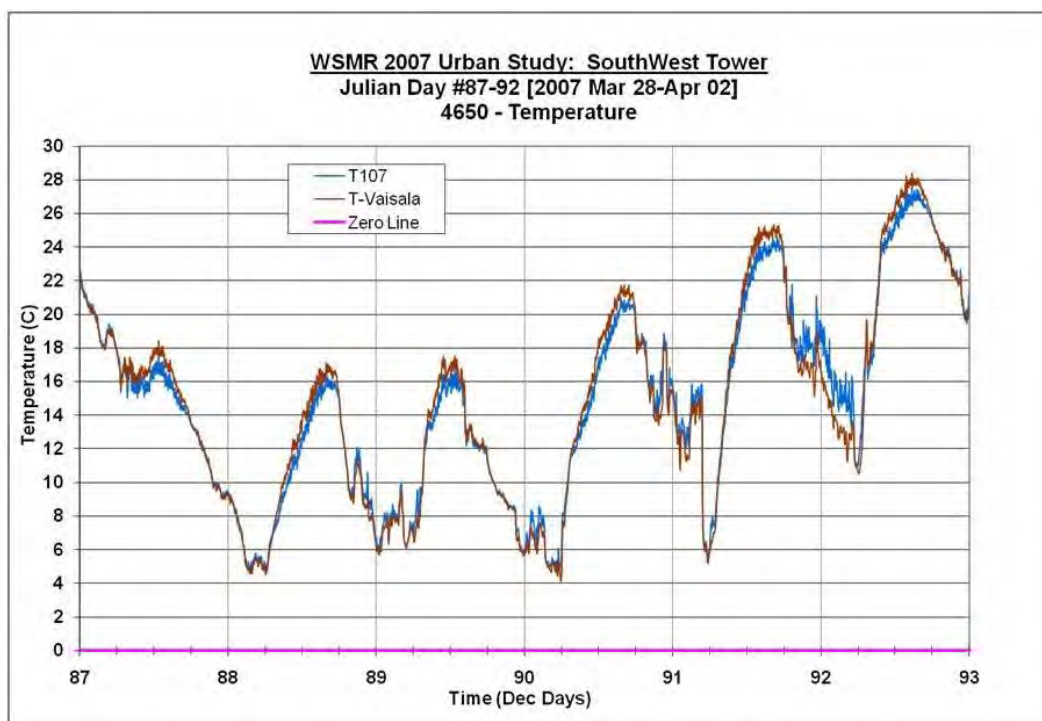


Figure B-3. SW tower: Temperature.

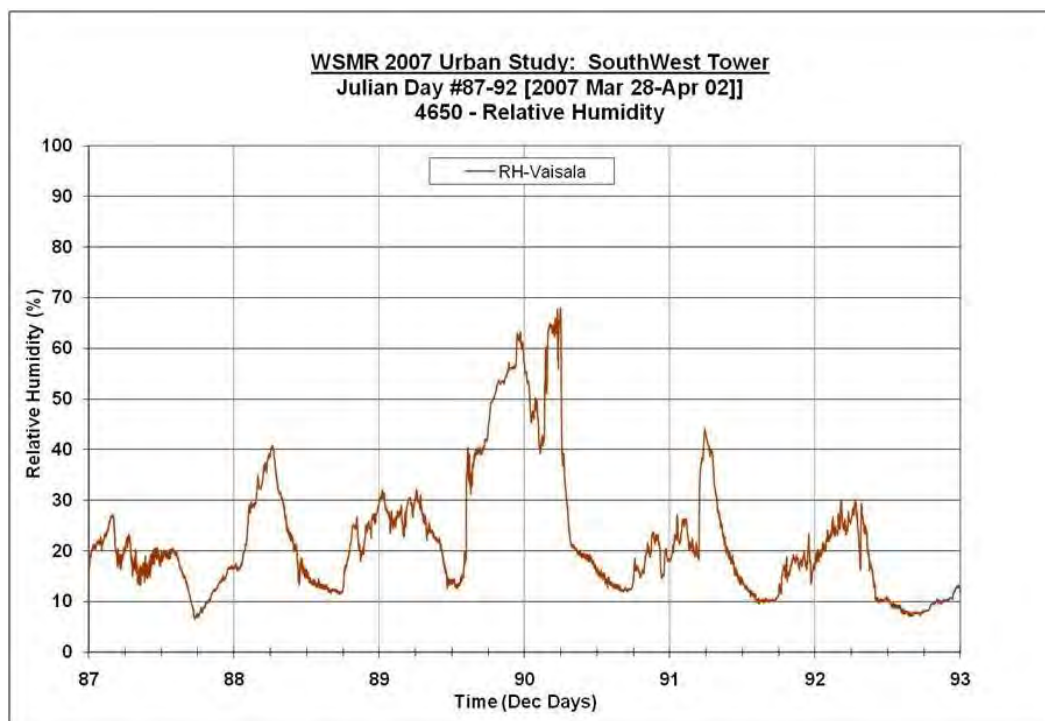


Figure B-4. SW tower: RH.

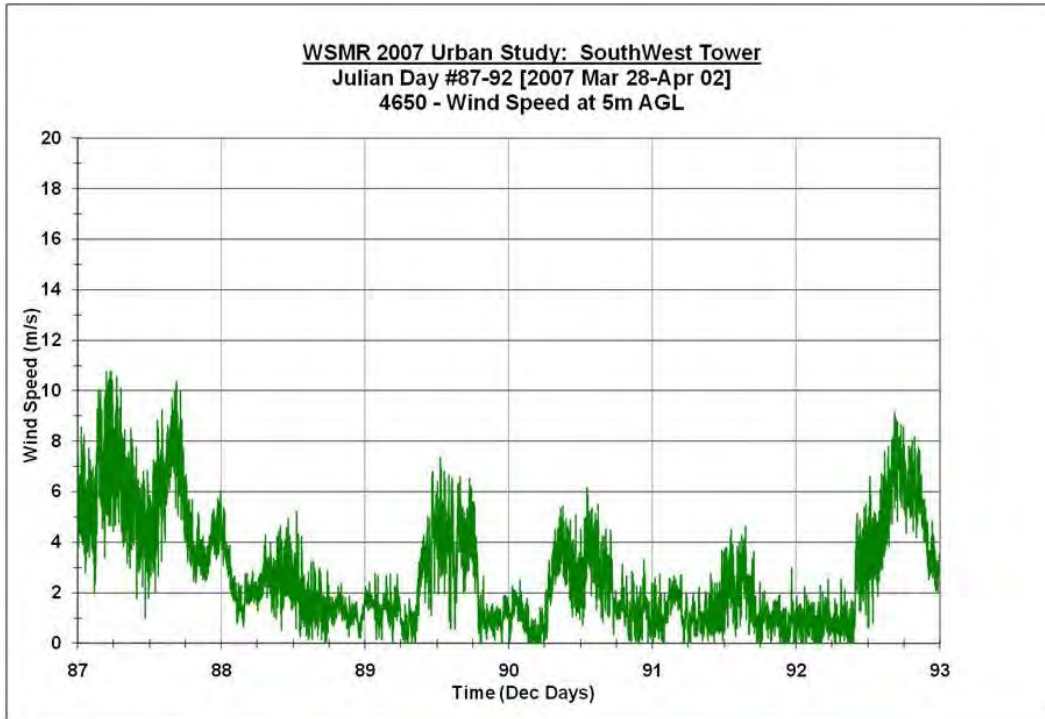


Figure B-5. SW tower: WS at 5-m AGL.

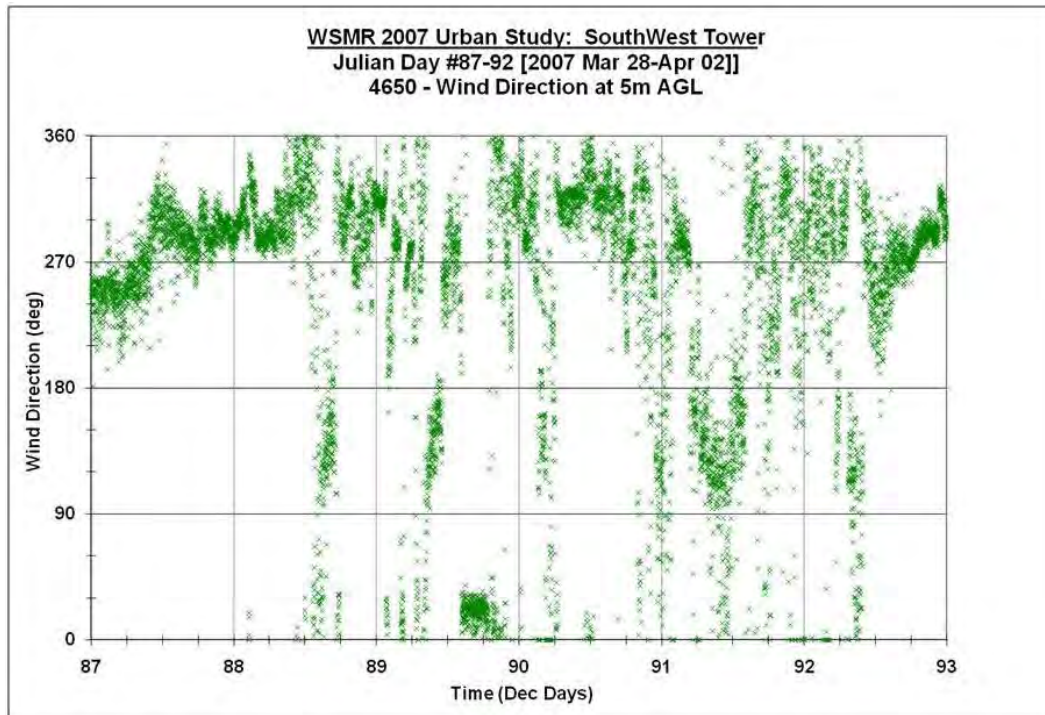


Figure B-6. SW tower: WD at 5-m AGL.



WSMR 2007 Urban Study (W07US): Thermodynamic (Campbell) Data								
W07US: SouthWest Tower (2 Radiometers)								
	Press (mb)	Temp 107Probe (deg.C)	Tvai 2m Vaisala (deg.C)	RH 2m Vaisala (%)	WS - 5m (m/s)	WD - 5m (deg)	Solar Rad (W/m2)	NetRad (W/m2)
<b>Sim Bomb Drill Day</b>	FULL DAY	070329	Julian #88					
Average	871.63	10.12	10.38	22.22	2.00	272.55	303.72	93.49
Standard Deviation	1.05	3.50	3.86	8.13	0.94	78.10	380.57	241.73
Maximum	873.22	16.441	17.44	40.87	5.38	359.9	992.39	573.51
Minimum	869.42	4.61	4.53	11.41	0	0	0.00	0.00
<b>Sim Bomb Drill</b>	1315-1425 LT	070329	Julian #88					
Average	871.11	14.53	15.37	13.35	1.65	184.15	877.14	470.67
Standard Deviation	0.17	0.52	0.40	0.37	0.86	130.63	42.20	31.01
Maximum	871.40	15.67	16.39	14.62	4.23	359.32	939.10	531.46
Minimum	870.75	13.62	14.70	12.69	0.32	2.87	801.25	411.95
	Press	T-107	T-Vai	RH-Vai	WS - 5m	WD - 5m	Solar Rad	NetRad
<b>Sim Bomb Drill Day</b>	FULL DAY	070330	Julian #89					
Average	870.64	10.66	10.81	33.65	2.30	196.53	226.75	71.09
Standard Deviation	1.59	3.23	3.67	14.37	1.63	122.20	342.70	209.88
Maximum	873.55	16.72	17.53	63.31	7.36	359.81	1070.60	642.57
Minimum	868.25	5.63	5.62	12.51	0	0	0.00	0.00
<b>Sim Bomb Drill</b>	1300-1345 LT	070330	Julian #89					
Average	868.43	15.79	16.46	14.08	4.48	276.97	487.89	224.29
Standard Deviation	0.10	0.32	0.41	0.68	1.11	18.98	340.53	230.31
Maximum	868.63	16.67	17.35	15.35	6.81	329.76	1016.00	589.99
Minimum	868.25	15.38	15.93	13.09	1.99	236.44	133.58	-48.01
	Press	T-107	T-Vai	RH-Vai	WS - 5m	WD - 5m	Solar Rad	NetRad
<b>Sim ACR Drill Day</b>	FULL DAY	070402	Julian #92					
Average	870.18	21.17	20.97	15.07	3.17	256.30	310.09	106.76
Standard Deviation	1.05	4.74	5.67	7.16	2.39	73.16	383.84	249.42
Maximum	871.87	27.546	28.39	30.20	9.0911	357.7	999.01	596.67
Minimum	867.99	10.931	10.55	7.11	0	0	0.00	0.00
<b>Sim ACR Drill</b>	1305-1320 LT	070402	Julian #92					
Average	869.98	26.18	27.23	9.14	3.68	238.34	950.00	537.34
Standard Deviation	0.11	0.28	0.13	0.31	0.87	21.01	5.13	10.13
Maximum	870.14	26.61	27.47	9.60	5.19	261.49	956.48	550.32
Minimum	869.80	25.67	26.98	8.66	2.56	199.25	940.80	516.88

Figure B-7. SW tower: Thermodynamic data statistical summary for the Drill Days and Drill periods.

## B-2 Roof Tripod

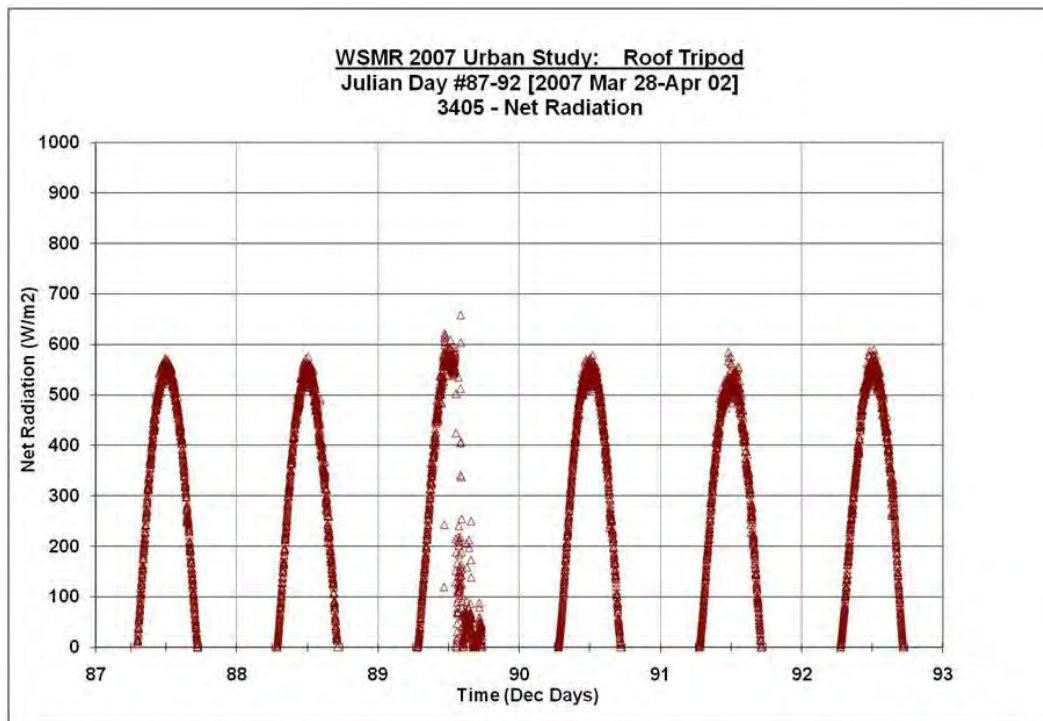


Figure B-8. Roof tripod: Net radiation.

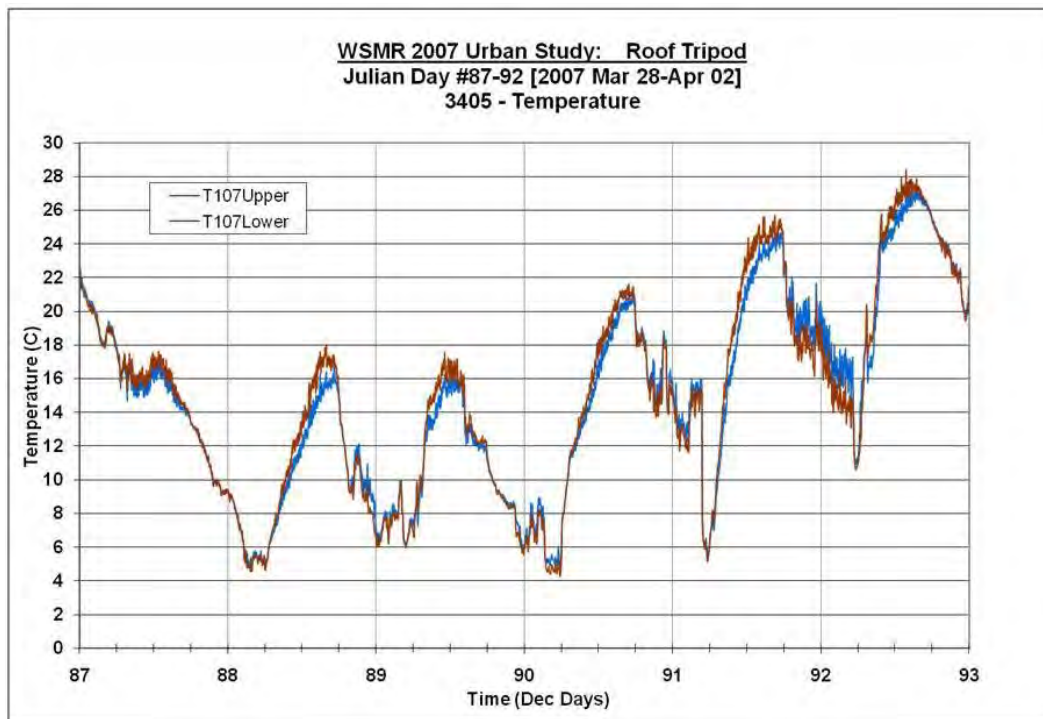


Figure B-9. Roof tripod: Temperature.



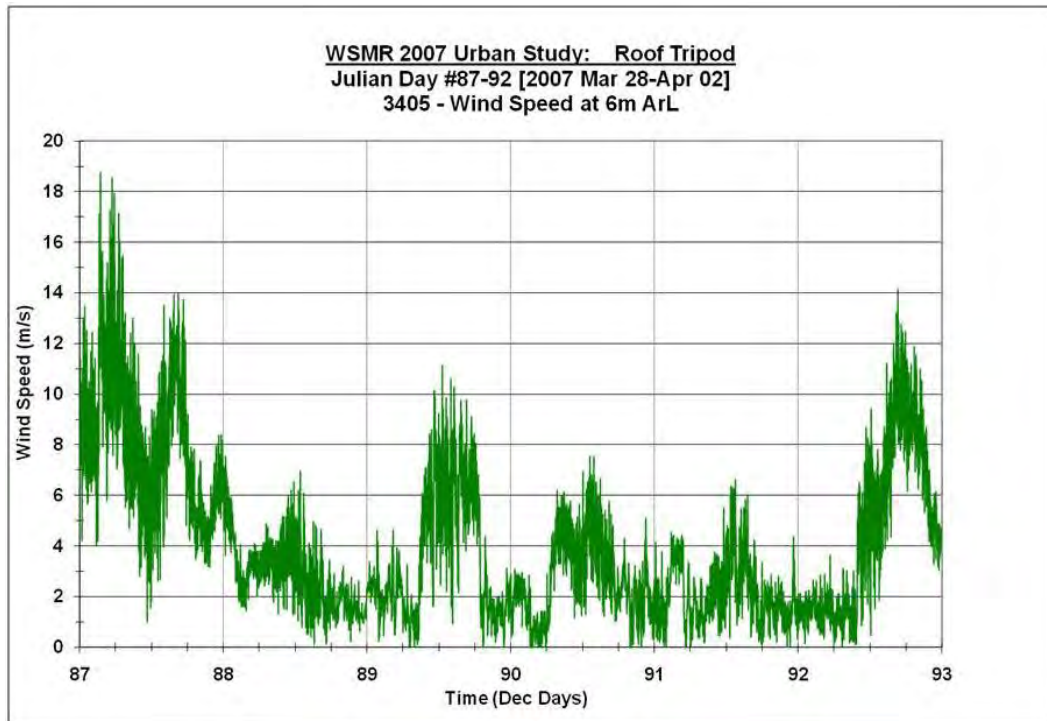


Figure B-10. Roof tripod: WS at 6-m ArL.

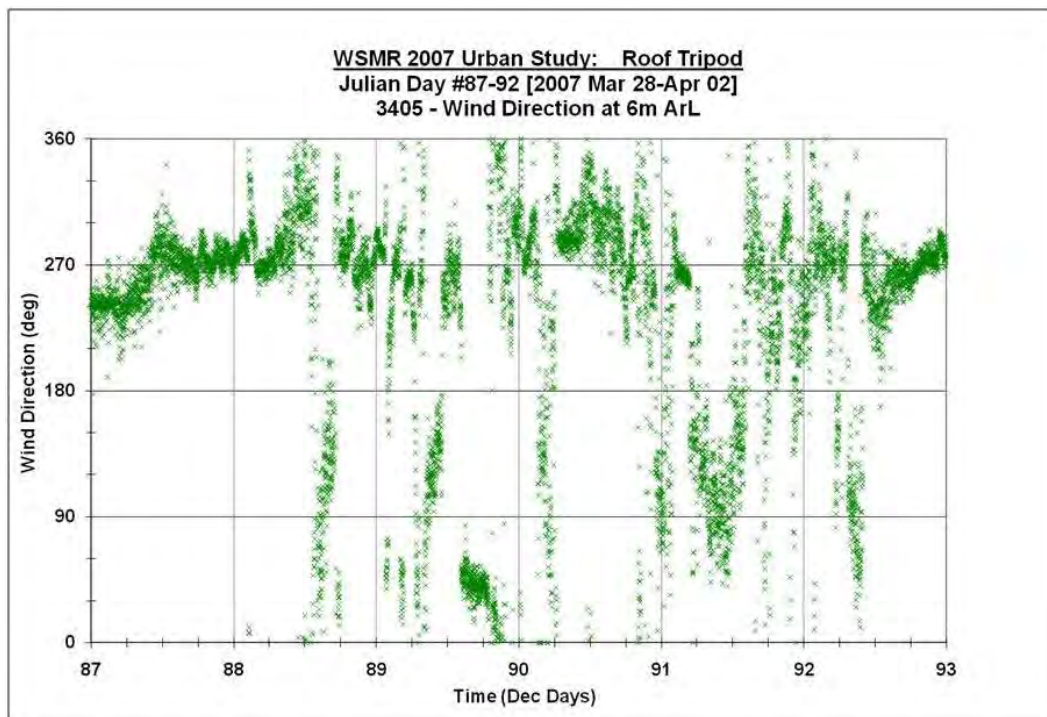


Figure B-11. Roof tripod: WD at 6-m ArL.

WSMR 2007 Urban Study (W07US): Thermodynamic (Campbell) Data						
W07US: Roof Tripod (1 Radiometer)						
	*no sensor Press (mb)	Temp 107Upper (deg-C)	Temp 107Lower (deg-C)	WS - 5m (m/s)	WD - 5m (deg)	Net Rad (W/m2)
<b>Sim FIRE Drill Day</b>	<b>FULL DAY</b>	<b>070329</b>	<b>Julian #88</b>			
Average	*	10.12	10.45	2.81	255.71	103.05
Standard Deviation	*	3.41	3.95	1.29	72.11	236.64
Maximum	*	16.82	18.03	7.46	359.01	574.96
Minimum	*	4.67	4.55	0.13	0.10	0.00
<b>Sim FIRE Drill</b>	<b>315-1425 L</b>	<b>070329</b>	<b>Julian #88</b>			
Average	*	14.11	15.65	2.49	184.09	452.20
Standard Deviation	*	0.50	0.60	1.26	120.87	36.62
Maximum	*	15.05	16.85	6.08	351.79	521.55
Minimum	*	13.13	14.12	0.52	6.03	381.32
	<b>Press</b>	<b>107Upper</b>	<b>107Lower</b>	<b>WS - 5m</b>	<b>WD - 5m</b>	<b>Net Rad</b>
<b>Sim Bomb Drill Day</b>	<b>FULL DAY</b>	<b>070330</b>	<b>Julian #89</b>			
Average	*	10.60	10.85	3.58	184.27	88.55
Standard Deviation	*	3.11	3.59	2.48	109.53	211.35
Maximum	*	16.334	17.577	11.032	359.94	657.82
Minimum	*	5.6806	5.5452	0	0	0
<b>Sim Bomb Drill</b>	<b>1300-1345 L</b>	<b>070330</b>	<b>Julian #89</b>			
Average	*	15.55	16.14	6.29	264.64	237.67
Standard Deviation	*	0.29	0.51	1.73	14.93	230.72
Maximum	*	16.19	17.18	9.83	313.50	593.70
Minimum	*	15.17	15.48	2.24	236.94	0.00
	<b>Press</b>	<b>107Upper</b>	<b>107Lower</b>	<b>WS - 5m</b>	<b>WD - 5m</b>	<b>Net Rad</b>
<b>Sim ACR Drill Day</b>	<b>FULL DAY</b>	<b>070402</b>	<b>Julian #92</b>			
Average	*	21.42	21.35	4.63	244.28	109.96
Standard Deviation	*	4.38	5.07	3.34	61.41	242.64
Maximum	*	27.359	28.414	14.076	359.91	588.89
Minimum	*	10.933	10.574	0.0098	9.3147	0
<b>Sim ACR Drill</b>	<b>1305-1320 L</b>	<b>070402</b>	<b>Julian #92</b>			
Average	*	25.94	27.22	5.55	233.62	526.42
Standard Deviation	*	0.37	0.40	1.18	15.52	13.95
Maximum	*	26.61	27.93	7.77	246.98	546.47
Minimum	*	25.36	26.57	3.48	196.04	502.05

Figure B-12. Roof tripod: Thermodynamic data statistical summary for the Drill Days and Drill periods.



### B-3 NE Tower

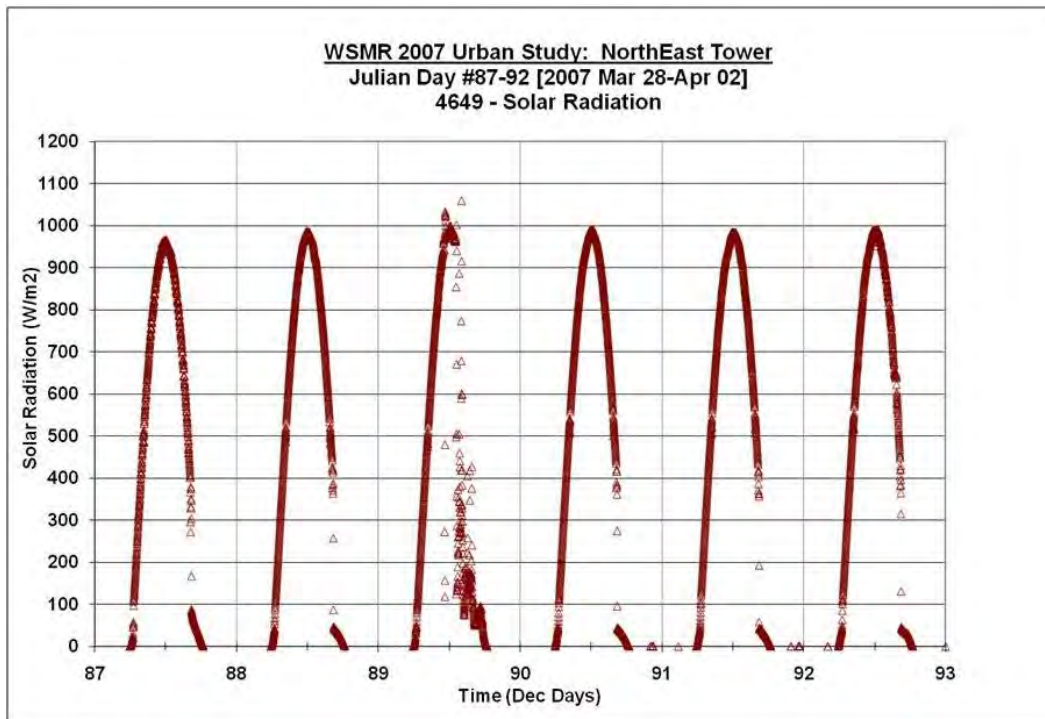


Figure B-13. NE tower: Solar radiation.

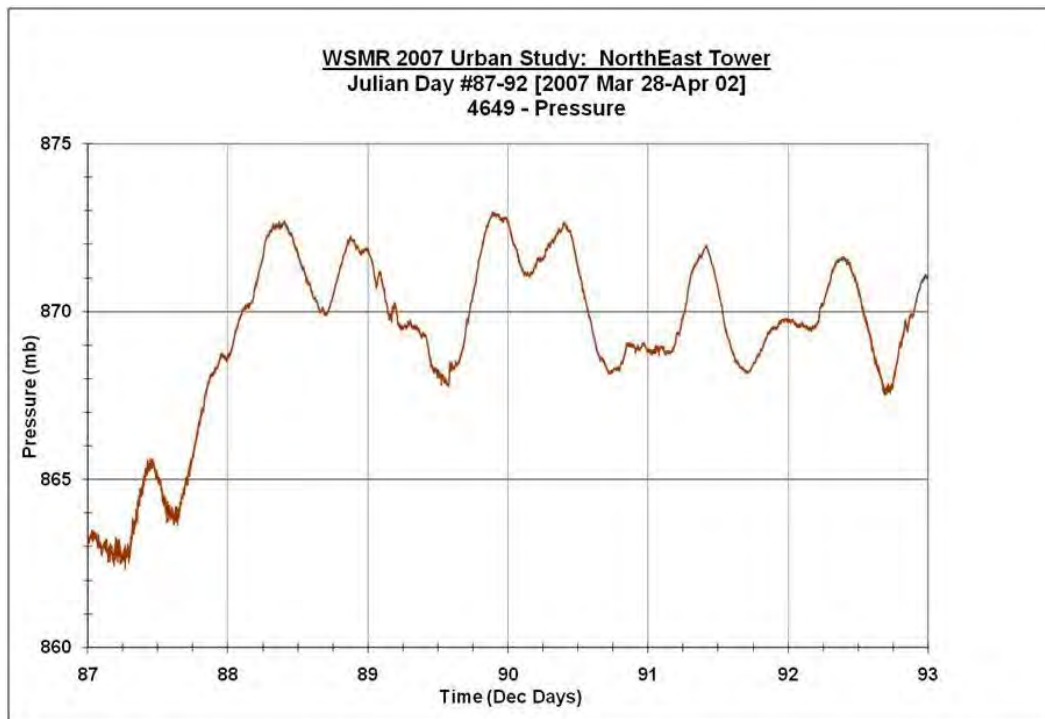


Figure B-14. NE tower: Pressure.

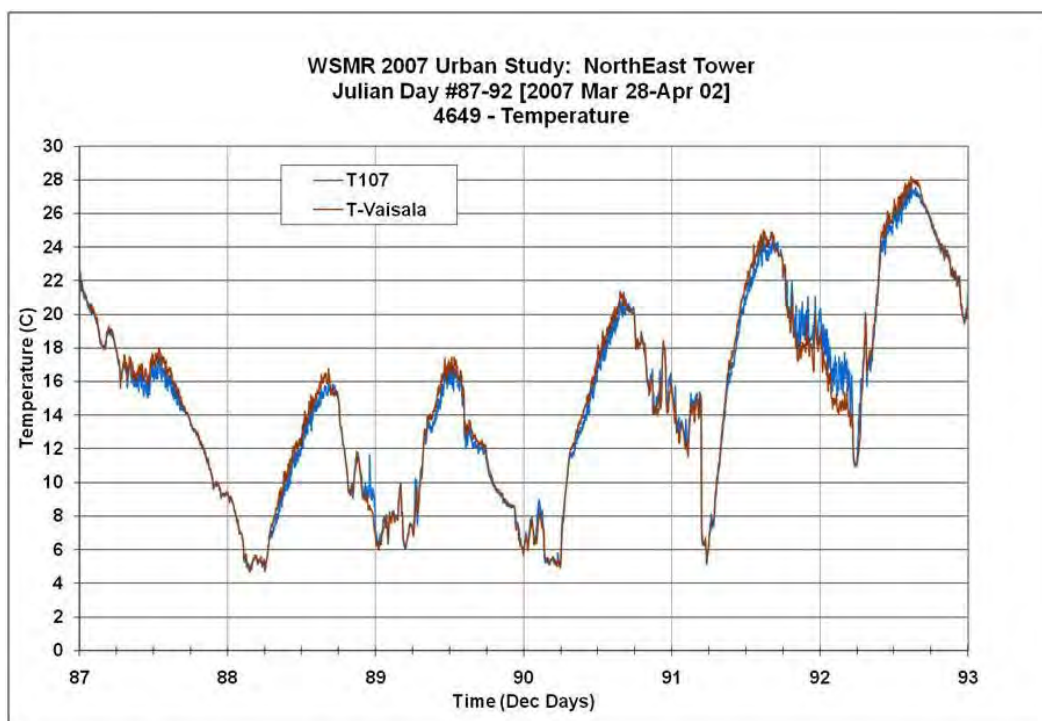


Figure B-15. NE tower: Temperature.

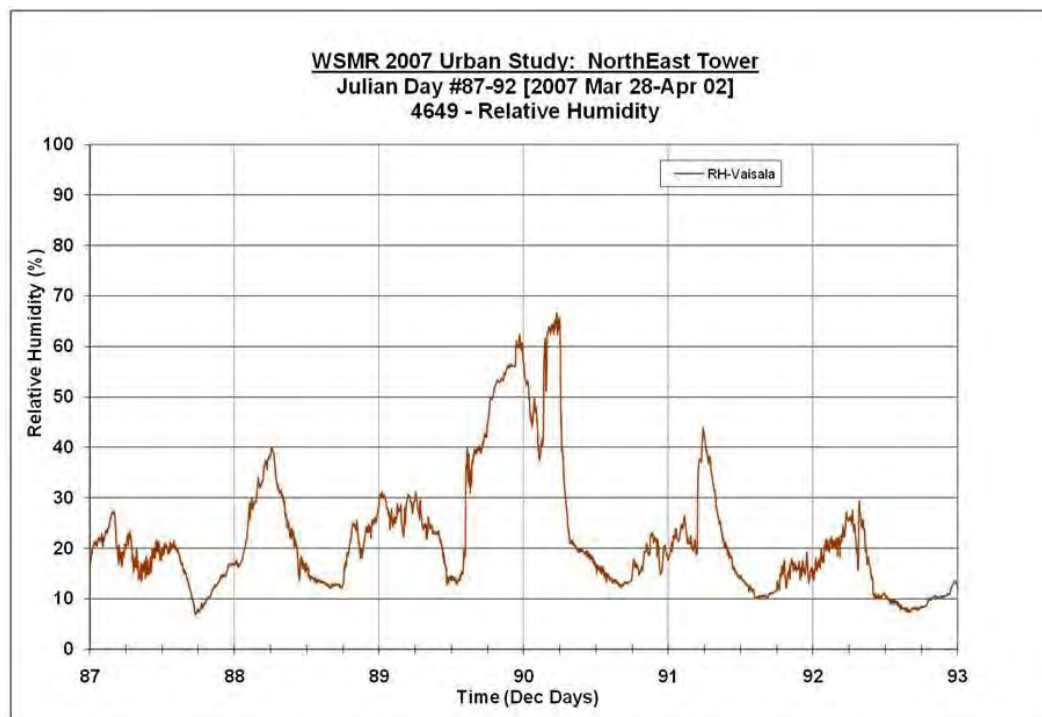


Figure B-16. NE tower: RH.

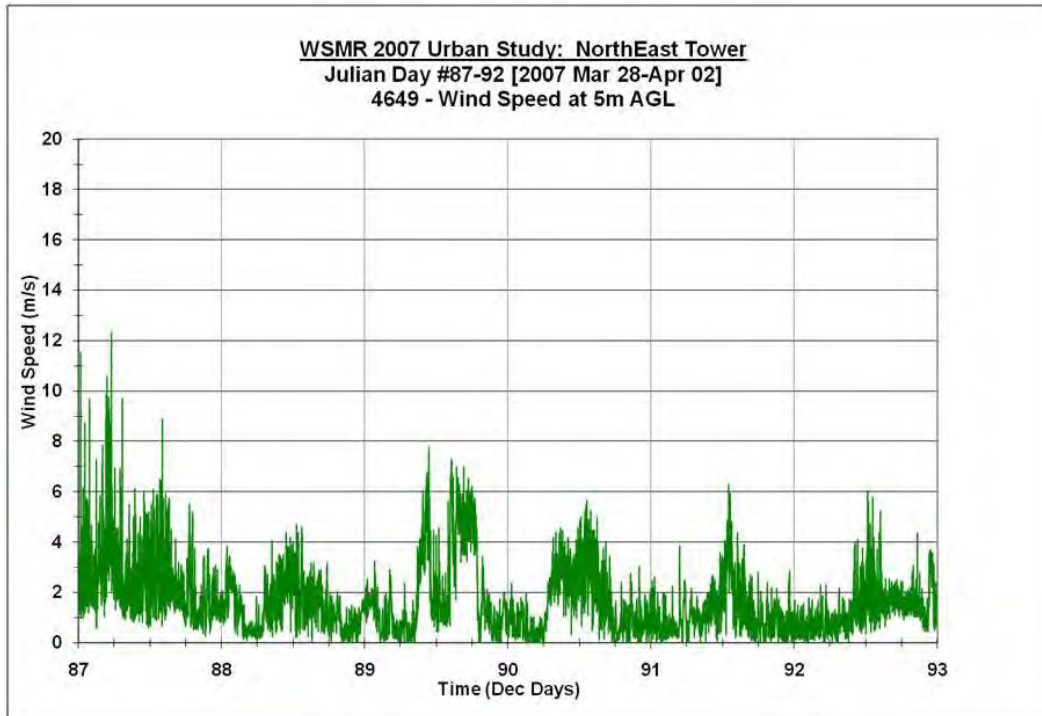


Figure B-17. NE tower: WS at 5-m AGL.

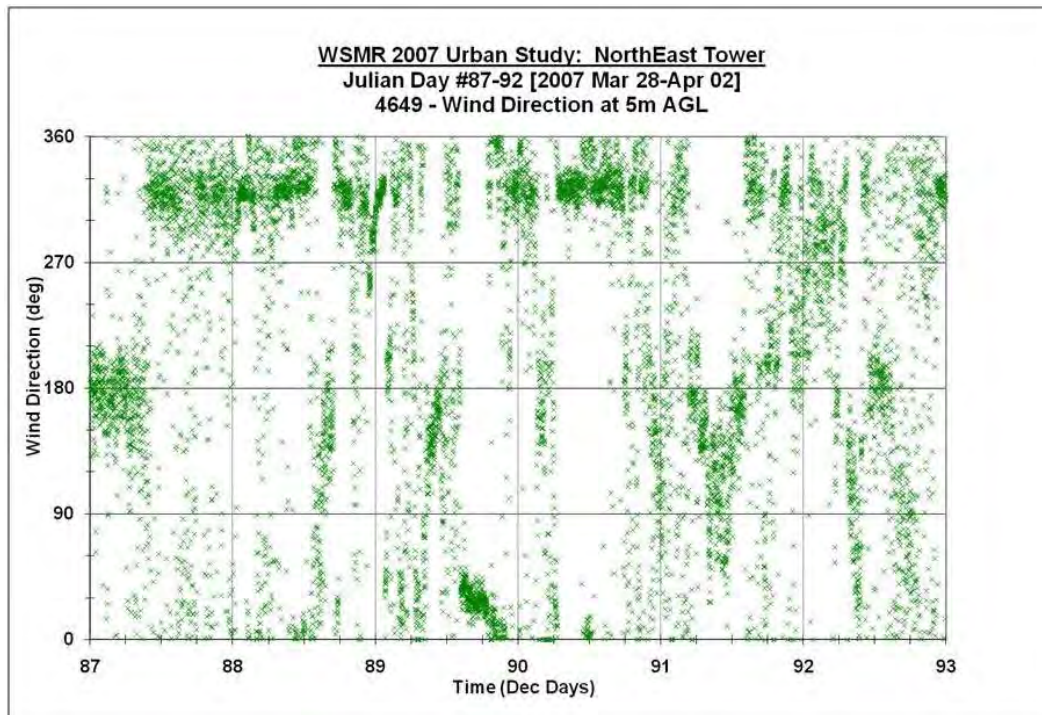


Figure B-18. NE tower: WD at 5-m AGL.



WSMR 2007 Urban Study (W07US): Thermodynamic (Campbell) Data							
W07US: NorthEast Tower (1 Radiometer)							
	Press (mb)	Temp 107Probe (deg-C)	Tvai 2m Vaisala (deg-C)	RH 2m Vaisala (%)	WS - 5m (m/s)	WD - 5m (deg)	Solar Rad (W/m2)
<b>Sim Bomb Drill Day</b>	FULL DAY	070329	Julian #88				
Average	871.15	10.16	10.34	22.16	1.42	255.28	292.46
Standard Deviation	1.05	3.34	3.52	7.78	0.92	106.52	382.08
Maximum	872.71	15.95	16.80	40.06	4.68	359.96	987.63
Minimum	868.60	4.68	4.77	12.10	0.00	0.00	0.00
<b>Sim Bomb Drill</b>	1315-1425 LT	070329	Julian #88				
Average	870.83	14.20	14.77	13.59	1.89	161.64	874.65
Standard Deviation	0.14	0.47	0.34	0.22	0.98	129.87	42.95
Maximum	871.12	14.84	15.35	14.23	4.59	358.93	931.46
Minimum	870.57	13.07	14.04	13.14	0.50	0.50	795.48
	Press	T-107	T-Vai	RH-Vai	WS - 5m	WD - 5m	Solar Rad
<b>Sim Bomb Drill Day</b>	FULL DAY	070330	Julian #89				
Average	870.16	10.73	10.95	33.58	2.09	169.89	225.26
Standard Deviation	1.56	3.21	3.49	14.25	1.81	126.52	341.65
Maximum	872.97	17.005	17.488	62.457	7.6832	359.68	1060
Minimum	867.77	5.6757	5.7942	12.8	0	0	0
<b>Sim Bomb Drill</b>	1300-1345 LT	070330	Julian #89				
Average	867.90	16.07	16.53	14.22	1.36	205.69	476.35
Standard Deviation	0.07	0.35	0.37	0.62	0.47	106.32	338.22
Maximum	868.02	16.81	17.33	15.25	2.75	353.92	1003.20
Minimum	867.77	15.46	15.98	13.18	0.70	3.31	125.25
	Press	T-107	T-Vai	RH-Vai	WS - 5m	WD - 5m	Solar Rad
<b>Sim ACR Drill Day</b>	FULL DAY	070402	Julian #92				
Average	869.84	21.47	21.33	14.39	1.32	214.25	298.83
Standard Deviation	1.11	4.49	5.11	6.09	0.84	102.79	385.75
Maximum	871.63	27.578	28.211	29.4	6.0254	359.53	993.5
Minimum	867.5	10.94	11.022	7.3493	0	0	0
<b>Sim ACR Drill</b>	1305-1320 LT	070402	Julian #92				
Average	869.79	26.26	26.83	9.52	2.35	185.96	945.54
Standard Deviation	0.06	0.45	0.32	0.30	1.28	21.72	3.68
Maximum	869.90	26.75	27.24	9.88	5.78	256.90	951.10
Minimum	869.69	25.44	26.24	8.88	0.84	165.32	938.89

Figure B-19. NE tower: Thermodynamic data statistical summary for the Drill Days and Drill periods.

## B-4 South Tower

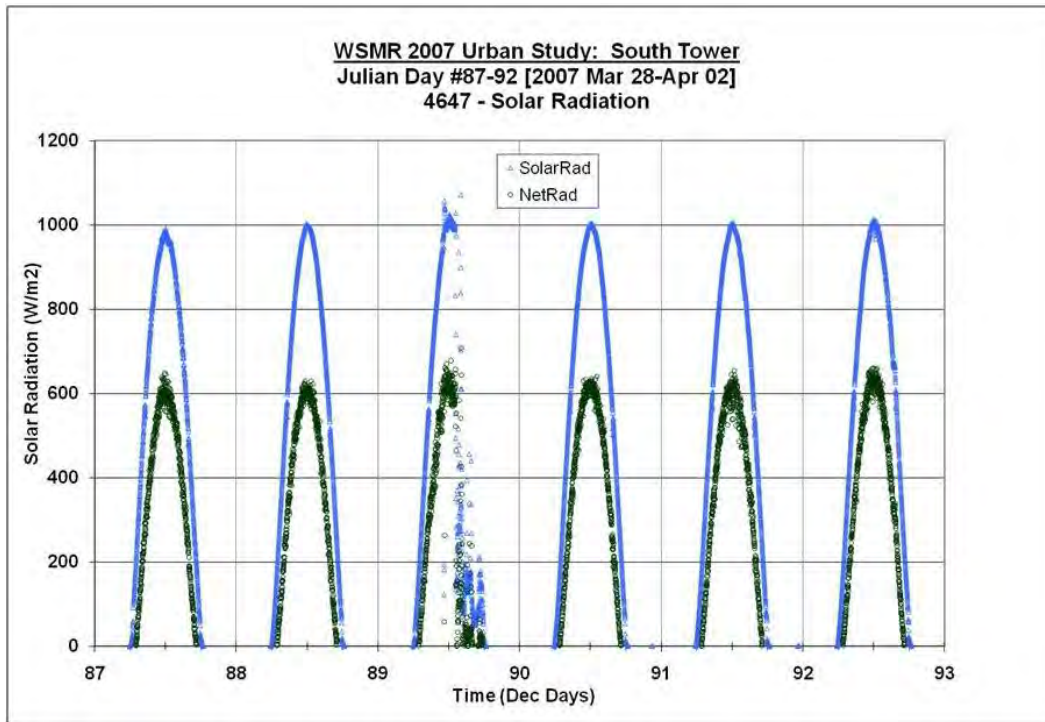


Figure B-20. South tower: Solar radiation.

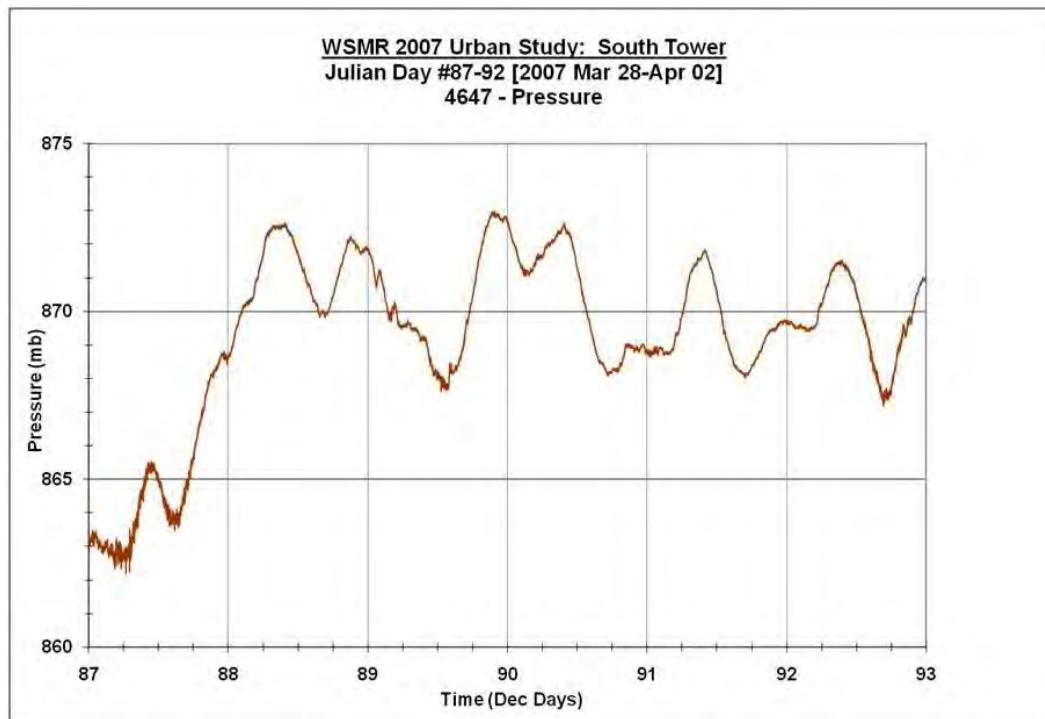


Figure B-21. South tower: Pressure.

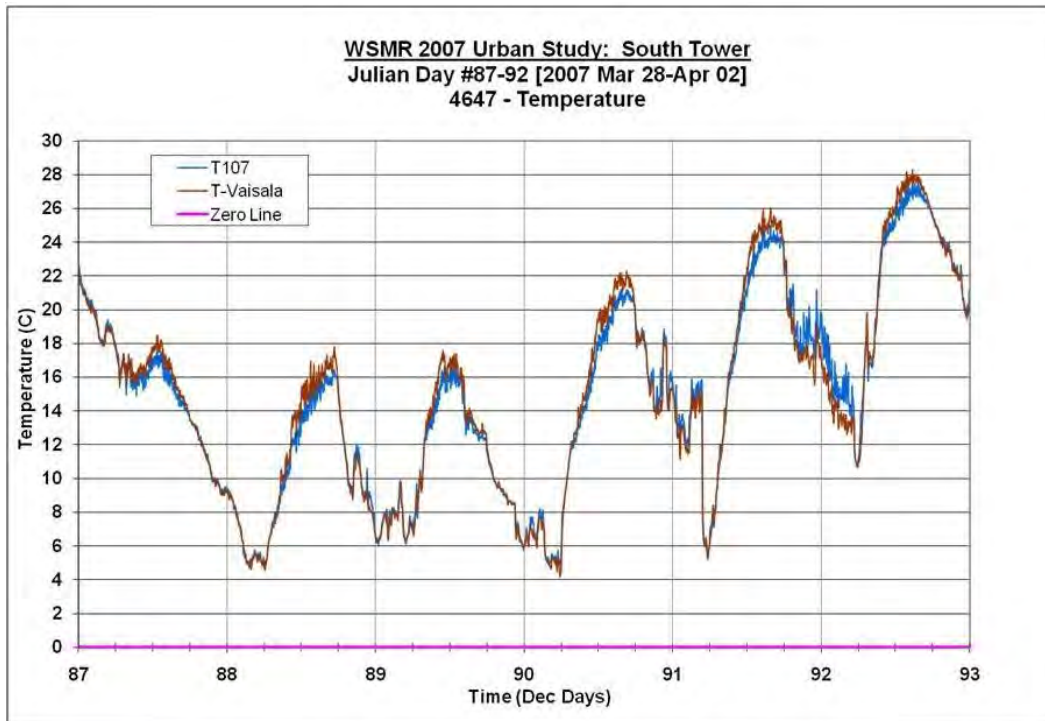


Figure B-22. South tower: Temperature.

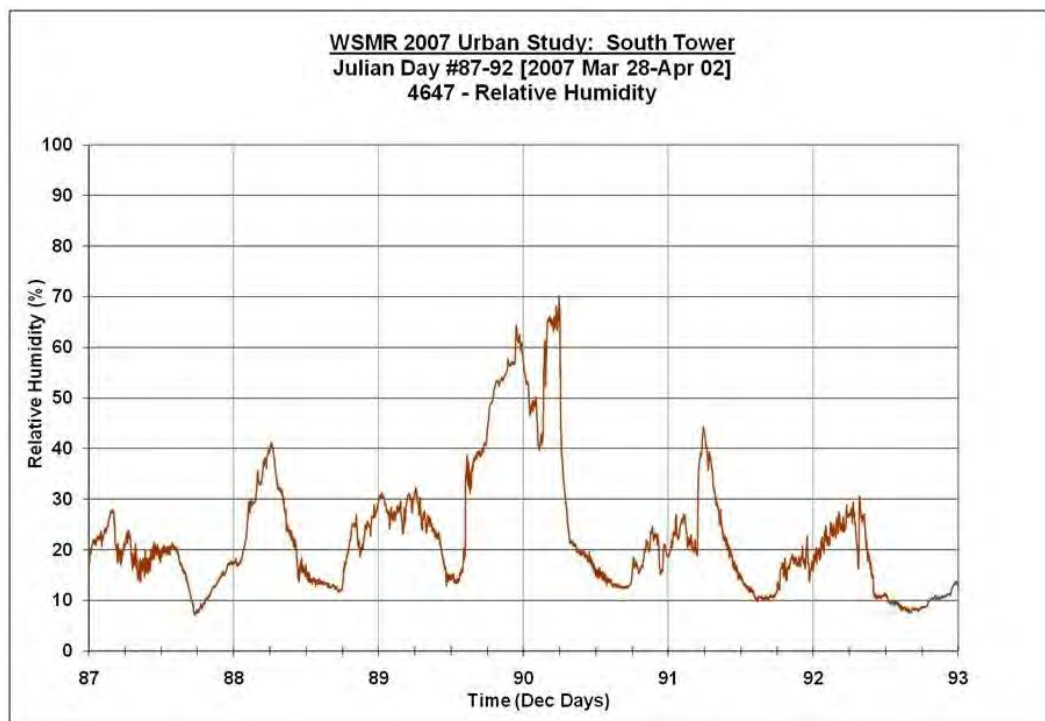


Figure B-23. South tower: RH.



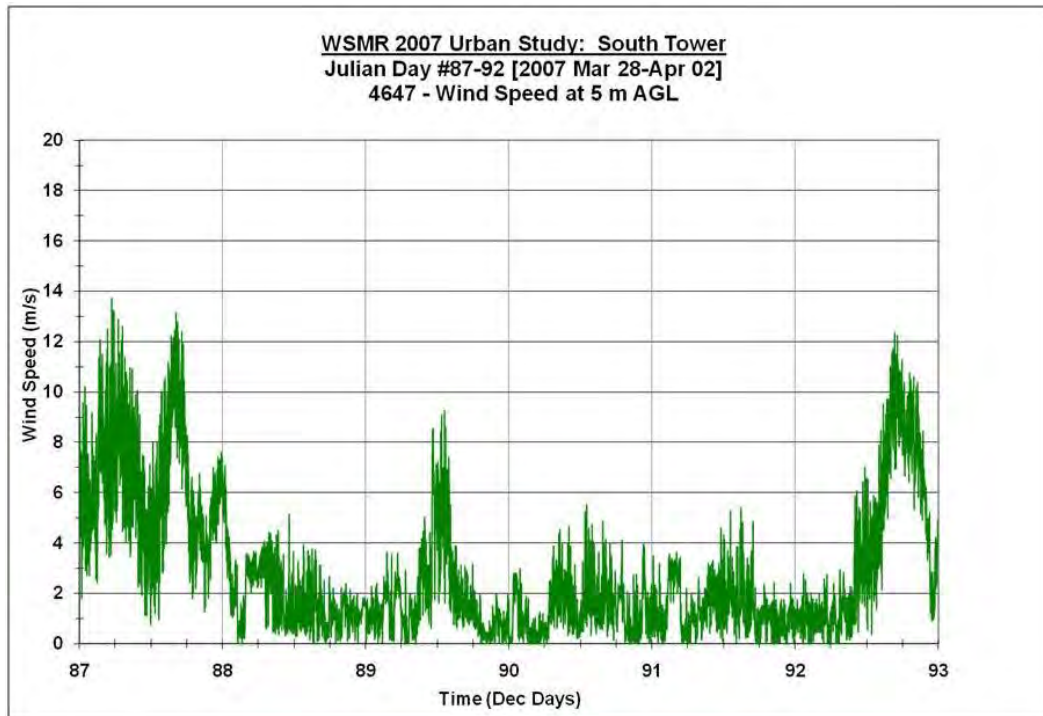


Figure B-24. South tower: WS at 5-m AGL.

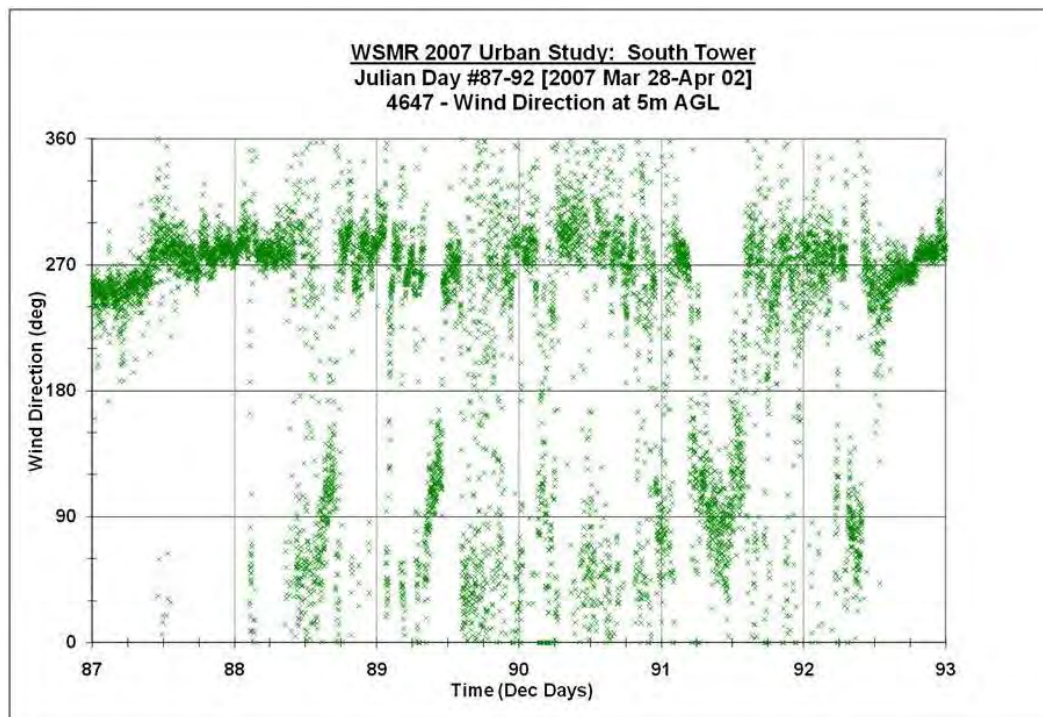


Figure B-25. South tower: WD at 5-m AGL.

WSMR 2007 Urban Study (W07US): Thermodynamic (Campbell) Data								
W07US: South Tower (2 Radiometers)								
	Press (mb)	Temp 107Probe (deg-C)	Tvai 2m Vaisala (deg-C)	RH 2m Vaisala (%)	WS - 5m (m/s)	WD - 5m (deg)	Solar Rad (W/m2)	NetRad (W/m2)
<b>Sim Full Drill Day</b>	FULL DAY	070329	Julian #88					
Average	871.16	10.30	10.63	22.53	1.86	227.11	308.36	103.18
Standard Deviation	1.04	3.59	3.97	8.18	1.20	95.29	382.26	270.45
Maximum	872.66	16.50	17.83	41.16	7.06	357.52	1001.50	629.46
Minimum	868.65	4.57	4.59	11.61	0.00	0.00	0.00	0.00
<b>Sim Full Drill</b>	1315-1425 LT	070329	Julian #88					
Average	870.77	14.78	15.66	13.65	1.54	131.94	888.71	506.55
Standard Deviation	0.16	0.52	0.57	0.31	0.91	107.47	42.95	37.47
Maximum	871.08	15.71	16.97	14.36	3.90	357.52	950.54	582.89
Minimum	870.48	13.81	14.88	12.74	0.33	10.19	811.19	410.04
	Press	T-107	T-Vai	RH-Vai	WS - 5m	WD - 5m	Solar Rad	NetRad
<b>Sim Bomb Drill Day</b>	FULL DAY	070330	Julian #89					
Average	870.14	10.75	11.01	33.80	1.89	198.37	229.28	77.31
Standard Deviation	1.59	3.27	3.61	14.15	1.72	102.61	345.16	237.06
Maximum	873	16.935	17.599	64.55	9.23	359.8	1071.1	707.97
Minimum	868.25	5.6256	5.6198	12.513	0	0	0.00	0.00
<b>Sim Bomb Drill</b>	1300-1345 LT	070330	Julian #89					
Average	867.81	15.84	16.41	14.69	5.64	265.91	489.94	241.52
Standard Deviation	0.09	0.31	0.45	0.81	1.57	13.85	347.01	252.26
Maximum	868.01	16.69	17.41	16.12	9.23	296.15	1027.40	657.16
Minimum	867.65	15.44	15.85	13.42	1.64	225.57	134.01	-35.80
	Press	T-107	T-Vai	RH-Vai	WS - 5m	WD - 5m	Solar Rad	NetRad
<b>Sim ACR Drill Day</b>	FULL DAY	070402	Julian #92					
Average	869.75	21.17	21.05	15.30	3.93	242.15	316.04	118.69
Standard Deviation	1.14	4.80	5.47	6.88	3.25	71.89	386.58	278.79
Maximum	871.53	27.676	28.329	30.607	12.353	358.28	1011.5	660.18
Minimum	867.19	10.836	10.676	7.5458	0	0	0.00	0.00
<b>Sim ACR Drill</b>	1305-1320 LT	070402	Julian #92					
Average	869.72	26.21	27.28	9.52	3.77	236.16	961.04	599.14
Standard Deviation	0.05	0.35	0.18	0.29	1.00	21.18	5.10	16.41
Maximum	869.80	26.79	27.63	10.02	5.88	260.13	969.00	630.48
Minimum	869.61	25.58	27.05	9.02	1.74	190.50	951.88	568.48

Figure B-26. South tower: Thermodynamic data statistical summary for the Drill Days and Drill periods.



## B-5 North Tower

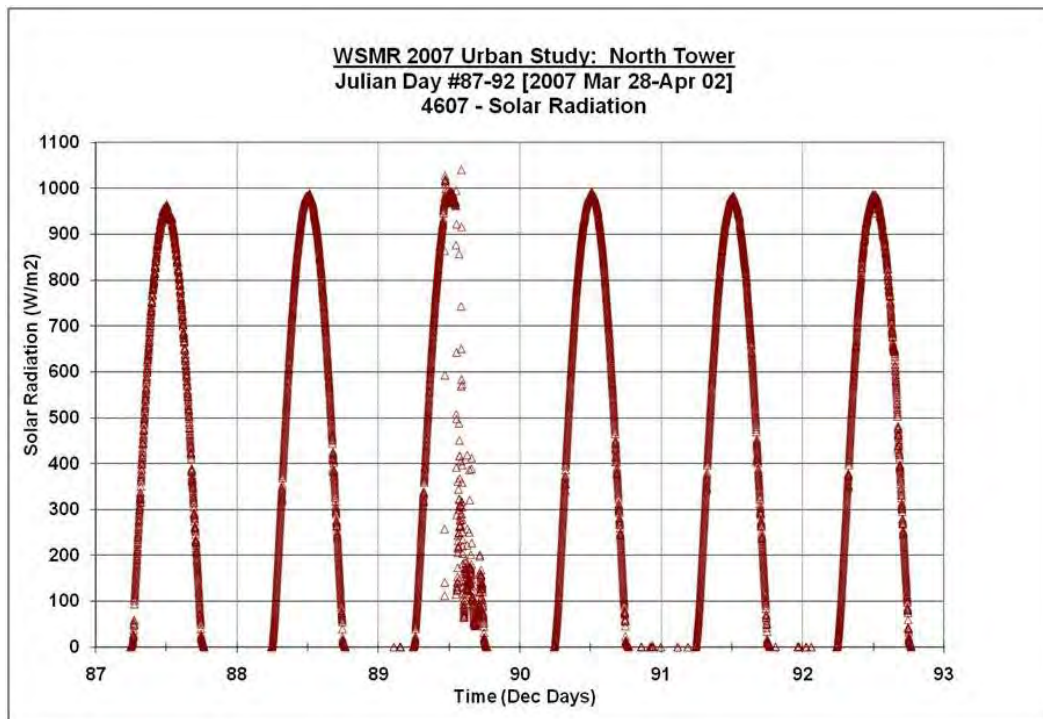


Figure B-27. North tower: Solar radiation.

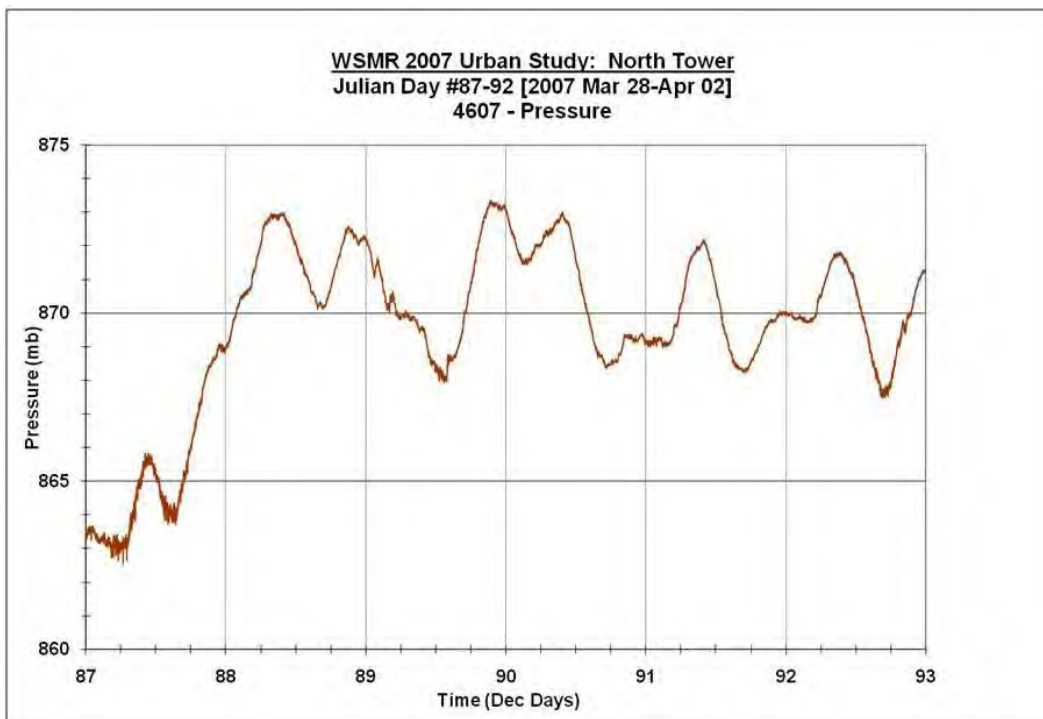


Figure B-28. North tower: Pressure.

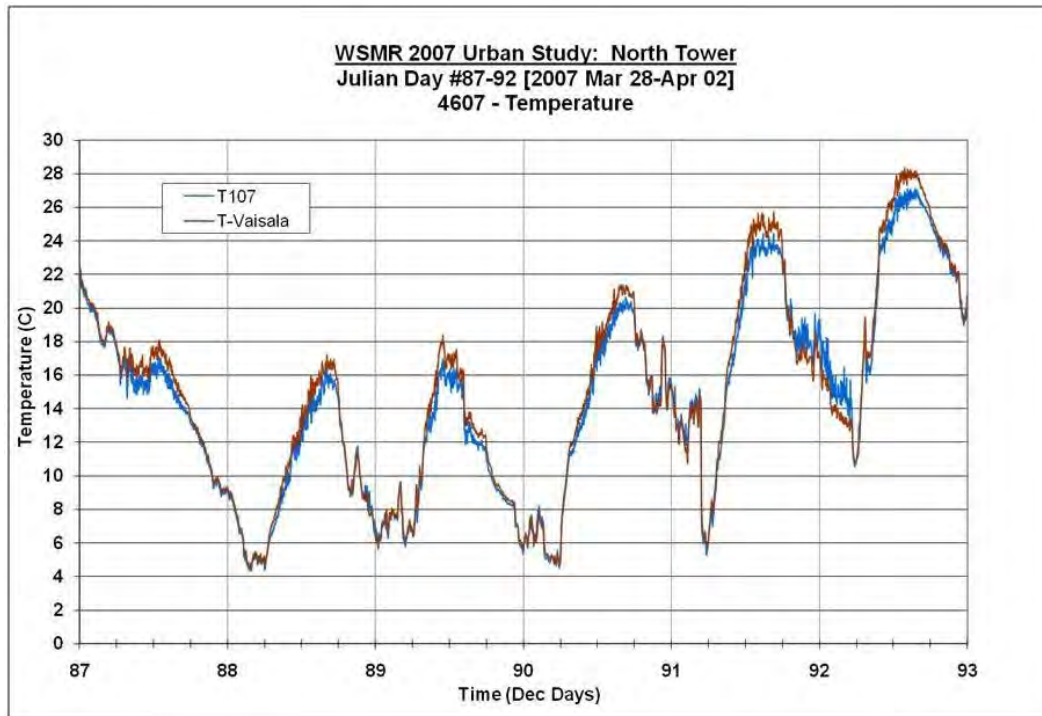


Figure B-29. North tower: Temperature.

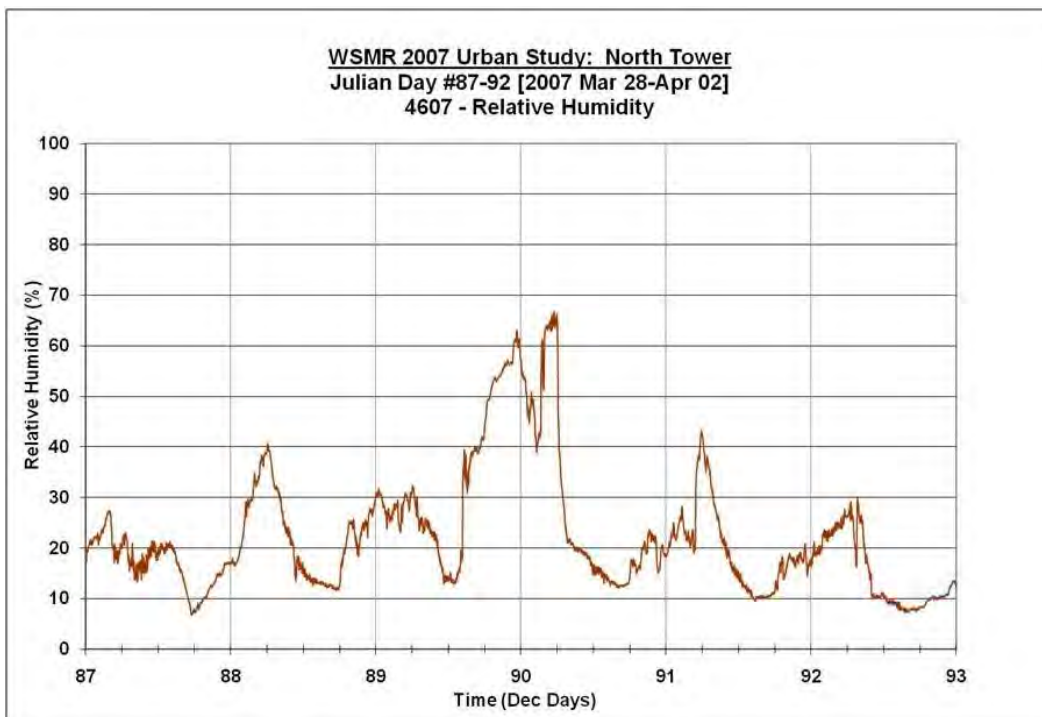


Figure B-30. North tower: RH.

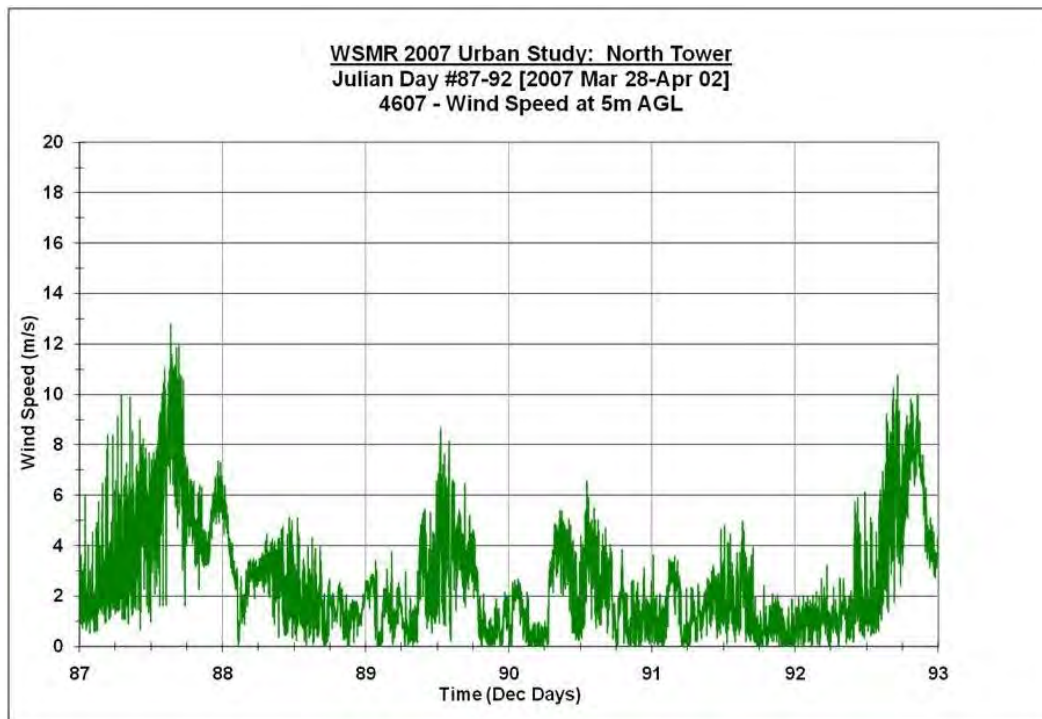


Figure B-31. North tower: WS at 5-m AGL.

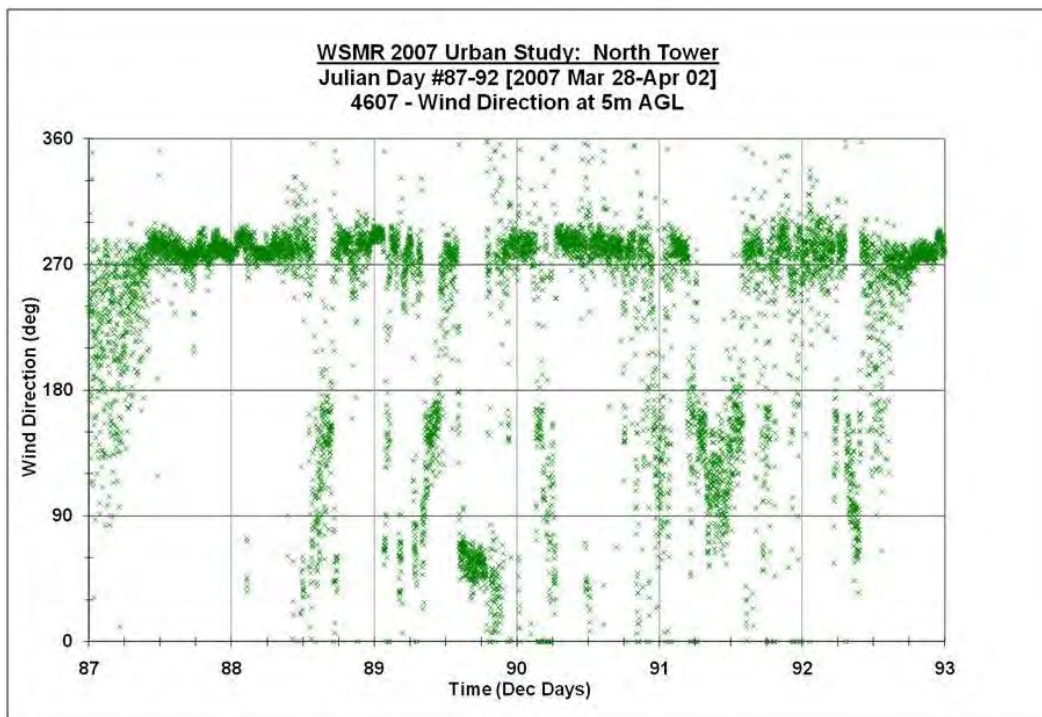


Figure B-32. North tower: WD at 5-m AGL.



WSMR 2007 Urban Study (W07US): Thermodynamic (Campbell) Data							
W07US: North Tower (1 Radiometer)							
	Press (mb)	Temp 107Probe (deg-C)	Tvai 2m Vaisala (deg-C)	RH 2m Vaisala (%)	WS - 5m (m/s)	WD - 5m (deg)	Solar Rad (W/m2)
<b>Sim FDR Drill Day</b>	FULL DAY	070329	Julian #88				
Average	871.48	9.86	10.28	22.51	2.19	251.33	304.29
Standard Deviation	1.06	3.51	3.78	8.04	1.18	70.65	377.02
Maximum	872.97	16.66	17.24	40.68	6.40	356.56	988.90
Minimum	868.94	4.36	4.55	11.62	0.00	0.00	0.00
<b>Sim FDR Drill</b>	1315-1425 LT	070329	Julian #88				
Average	871.10	14.20	15.16	13.45	1.68	157.84	877.77
Standard Deviation	0.15	0.50	0.40	0.32	0.92	102.42	40.12
Maximum	871.41	15.29	16.02	14.17	3.95	356.56	934.82
Minimum	870.83	13.14	14.36	12.67	0.00	0.00	801.60
	Press	T-107	T-Vai	RH-Vai	WS - 5m	WD - 5m	Solar Rad
<b>Sim Bomb Drill Day</b>	FULL DAY	070330	Julian #89				
Average	870.48	10.46	10.99	33.70	2.14	183.57	224.38
Standard Deviation	1.60	3.33	3.74	14.30	1.61	103.23	337.69
Maximum	873.34	16.967	18.408	63.115	8.6567	358.04	1040.8
Minimum	867.93	5.357	5.5988	12.948	0	0	0
<b>Sim Bomb Drill</b>	1300-1345 LT	070330	Julian #89				
Average	868.11	15.60	16.50	14.34	4.08	267.03	469.56
Standard Deviation	0.08	0.40	0.61	0.86	1.73	23.74	341.03
Maximum	868.30	16.46	17.56	15.66	7.61	294.96	994.94
Minimum	867.93	15.02	15.72	13.10	0.88	152.35	115.04
	Press	T-107	T-Vai	RH-Vai	WS - 5m	WD - 5m	Solar Rad
<b>Sim ACR Drill Day</b>	FULL DAY	070402	Julian #92				
Average	869.97	20.87	21.12	15.02	3.19	248.71	310.04
Standard Deviation	1.17	4.82	5.55	6.84	2.64	61.32	379.04
Maximum	871.8	27.125	28.359	29.916	10.731	358.62	987.82
Minimum	867.48	10.567	10.824	7.3375	0	0	0
<b>Sim ACR Drill</b>	1305-1320 LT	070402	Julian #92				
Average	869.86	26.43	27.80	9.32	1.27	197.28	941.14
Standard Deviation	0.04	0.23	0.16	0.22	0.59	51.73	4.41
Maximum	869.91	26.90	28.06	9.65	2.97	285.50	947.46
Minimum	869.79	26.09	27.52	8.98	0.50	122.40	932.33

Figure B-33. North tower: Thermodynamic data statistical summary for the Drill Days and Drill periods.

---

## **Appendix C. *W07US* Dynamic Data (Sonic) by Disaster Response Drill Day (2007 March 29, March 30, April 2), and Each Drill Period**

---

This appendix displays the *W07US* dynamic data (sonic) by Disaster Response Drill Day and by each drill period. The subdivisions include:

- C-1 *W07US* Dynamic Data, 2007 March 29 (JD# 88)–Fire Drill
- C-2 *W07US* Dynamic Data, 2007 March 30 (JD# 89)–Simulated Bomb Threat Drill
- C-3 *W07US* Dynamic Data, 2007 April 02 (JD# 92)–Simulated Airborne Chemical Release Drill

These time series were sampled at 10-, -5 and 2.5-m AGL, unless otherwise noted. The instrument acquiring data was an RM Young Ultrasonic Anemometer 81000, which sampled at 20 Hz. These data were post-processed into 1-min averages that were time-aligned with the thermodynamic dataset. To help interpret the data, three urban airflow features frame the data presented:

- The Fetch Flow, which is an unobstructed airflow on the ~~up~~“upwind” side of a building.
- The Cavity Flow or flow reversal, which is a building leeward feature created by the building structure interrupting of the fetch airflow. This pattern generally manifests with upper level winds (i.e., 10-m AGL) in the direction and with similar magnitude to the fetch flow, and low level winds (i.e., 2.5-m AGL) in the reverse direction with slower velocities.
- The Re-attachment Zone (RAZ), which is a threshold on the building leeward, beyond which the leeward wind resumes its original pre-building, fetch-flow character.

The Fetch Flow was generally from the south and SW direction. Therefore, the SW tower was utilized as the ~~Fetch Flow~~“representative”. The downwind or leeward direction was on the east side for these drills. Therefore, the Cavity Flow data were sampled from the NE and SE towers. The downwind flow resumed its original character, a little further east than the cavity flow towers. Sensors placed at about 2-m AGL on three independent tripods captured the north, central and southern portions of this RAZ data.

### C-1 W07US Dynamic Data, 2007 March 29 (JD# 88)–Fire Drill

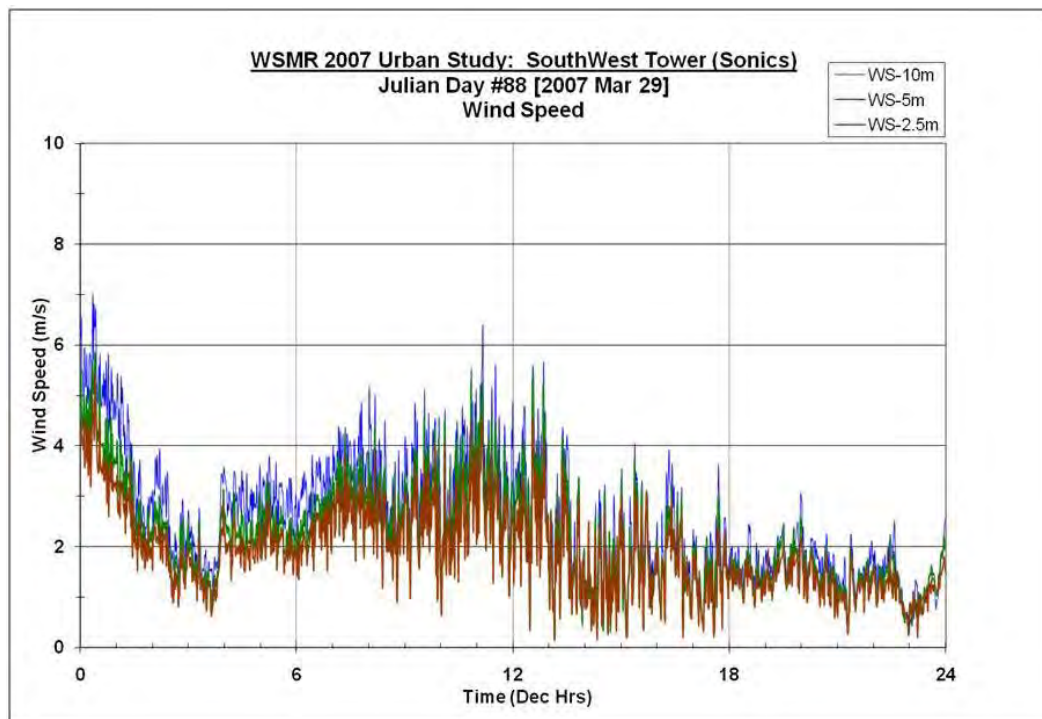


Figure C-1. SW tower (Sonics): WS (March 29).

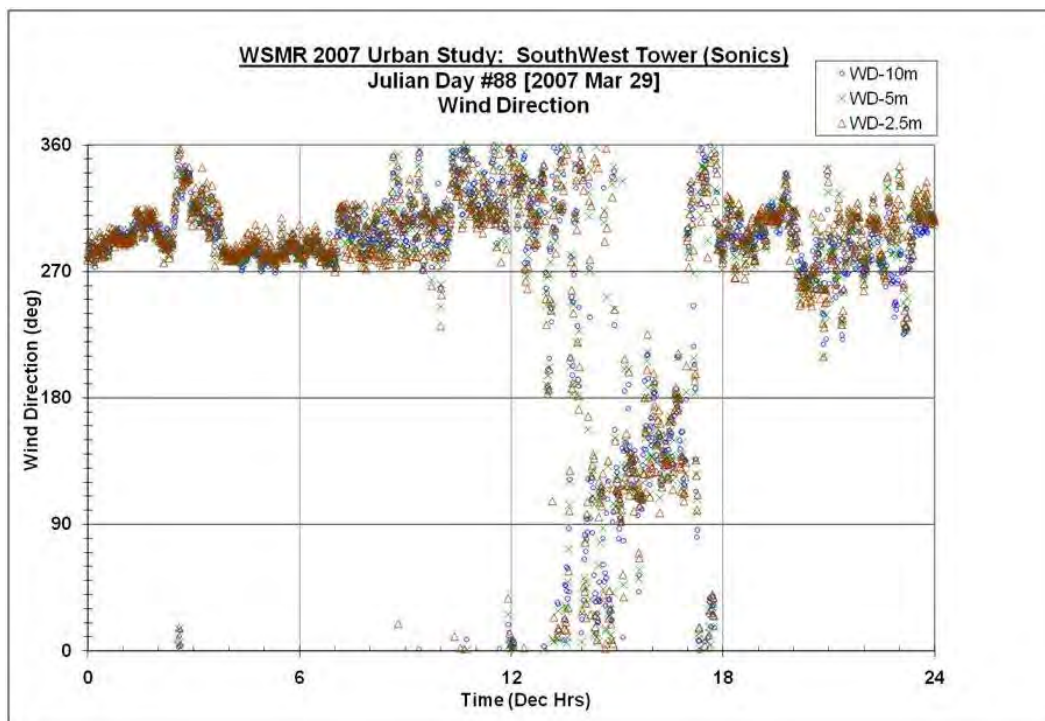


Figure C-2. SW tower (Sonics): WD (March 29).



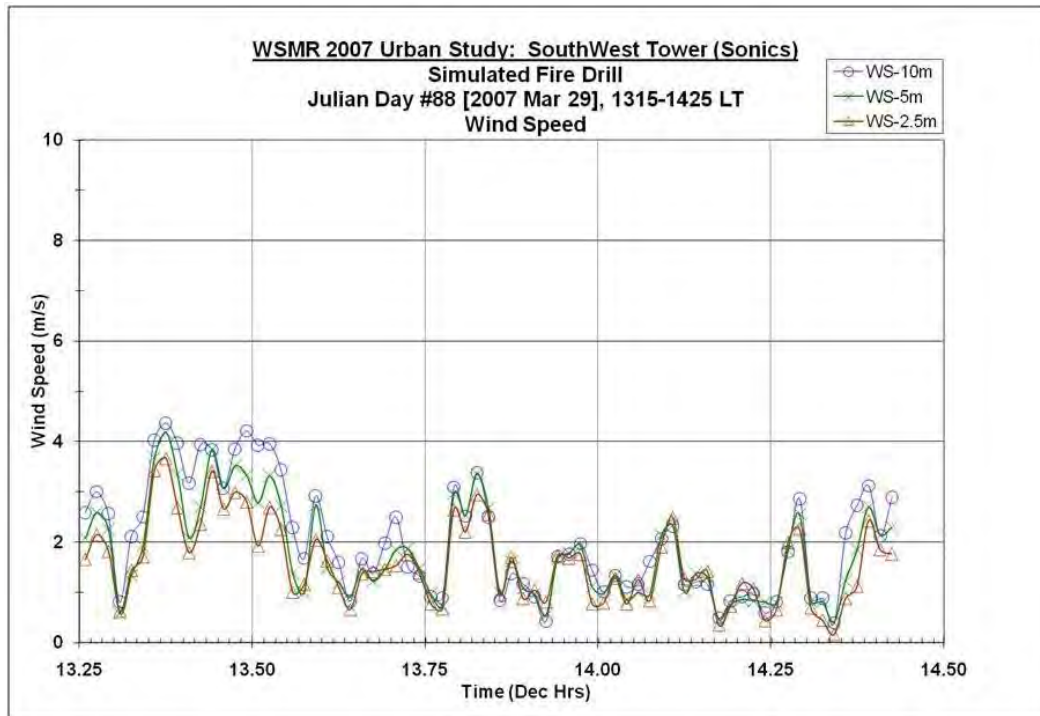


Figure C-3. SW tower (Sonics): Fire Drill Period–WS (March 29).

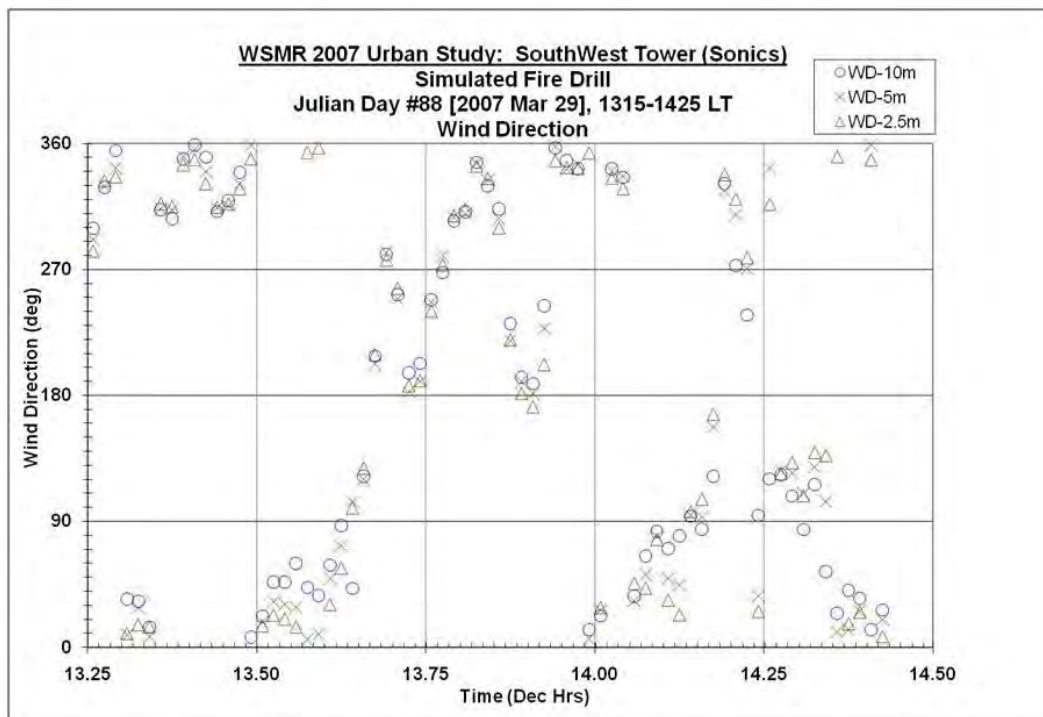


Figure C-4. SW tower (Sonics): Fire Drill Period–WD (March 29).

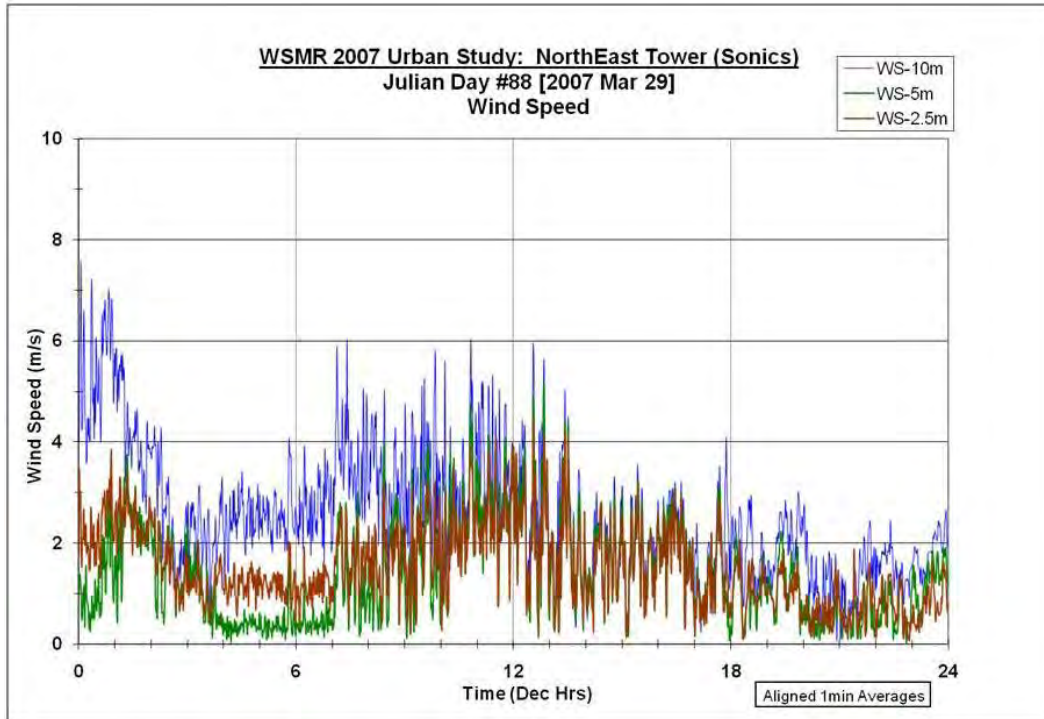


Figure C-5. NE tower (Sonics): WS (March 29).

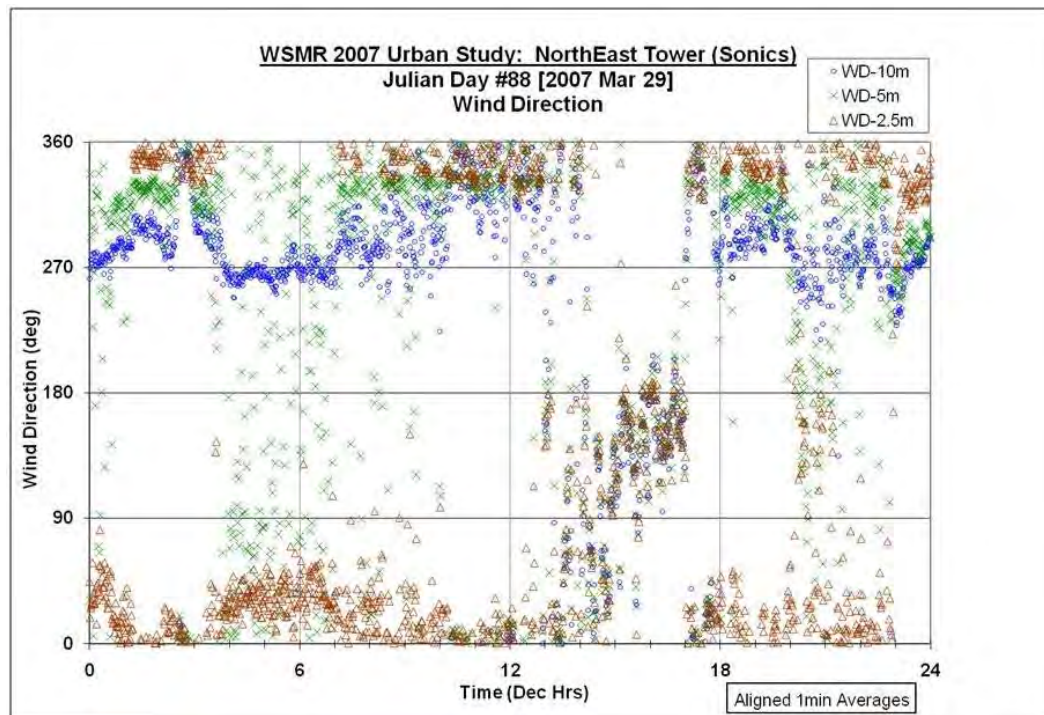


Figure C-6. NE tower (Sonics): WD (March 29).

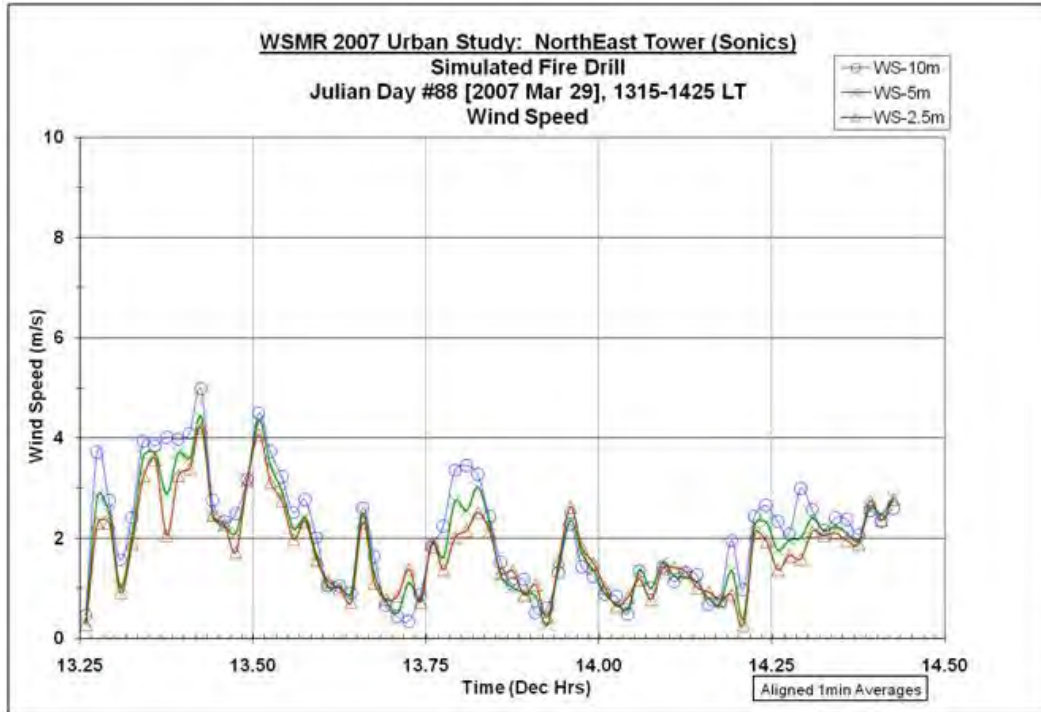


Figure C-7. NE tower (Sonics): Fire Drill Period–WS (March 29).

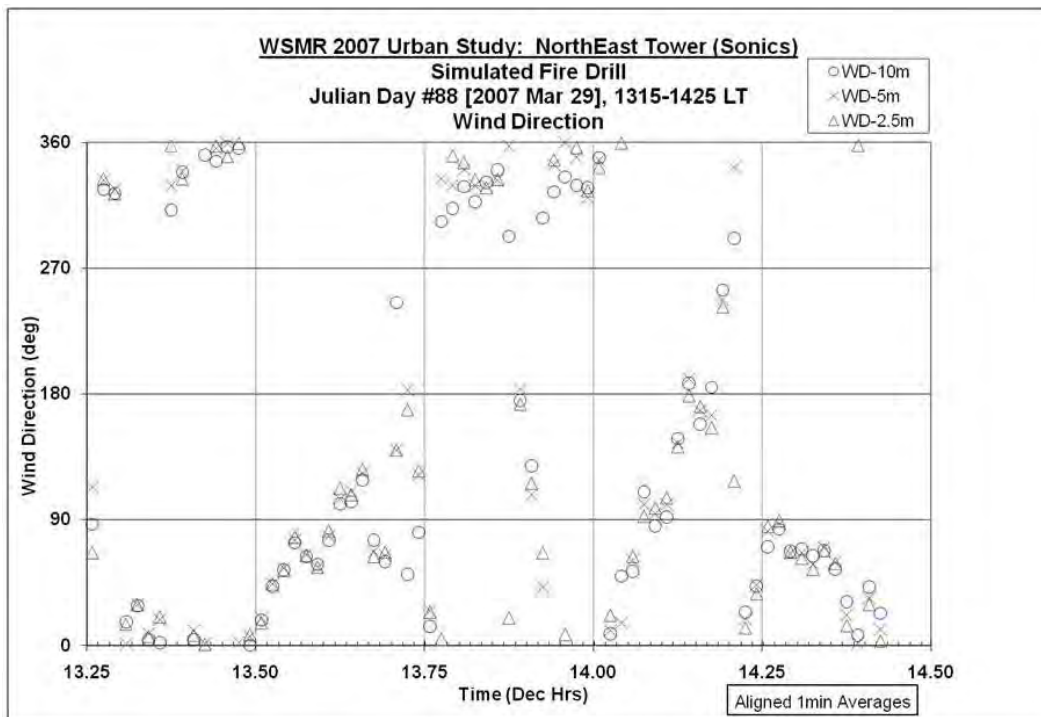


Figure C-8. NE tower (Sonics): Fire Drill Period–WD (March 29).

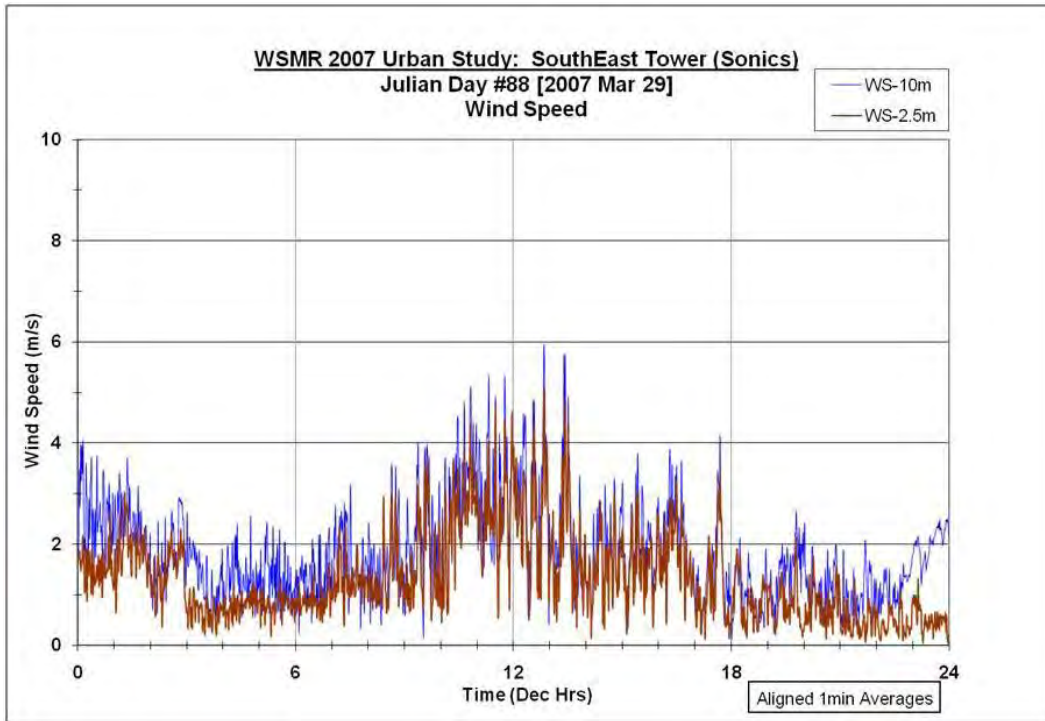


Figure C-9. SE tower (Sonics): WS (March 29).

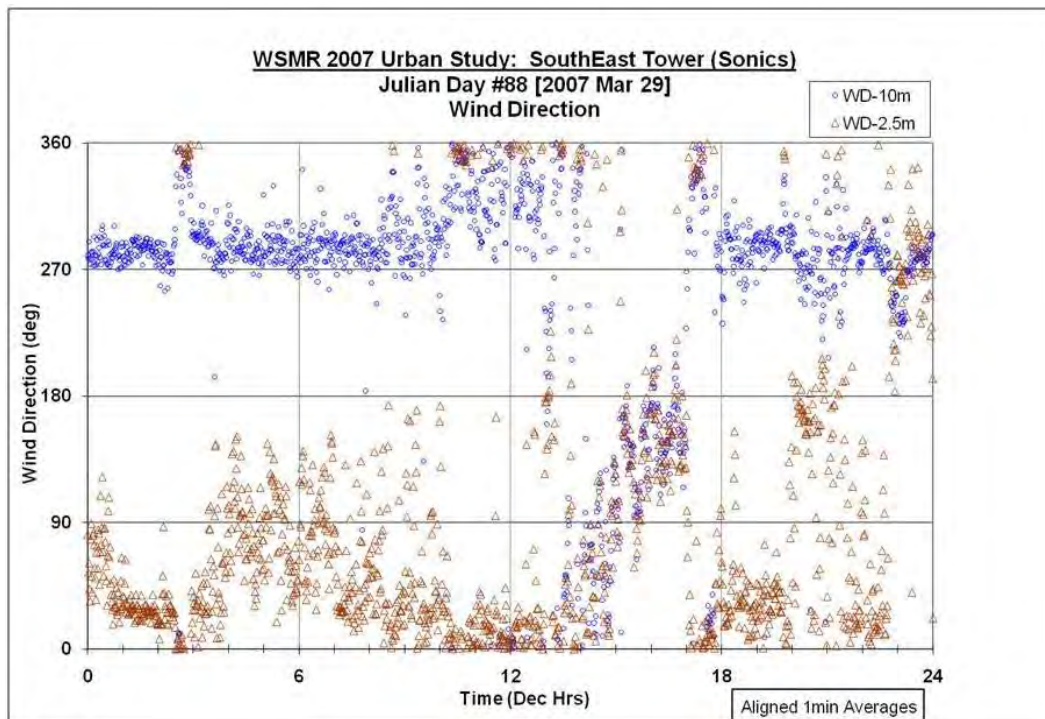


Figure C-10. SE tower (Sonics): WD (March 29).



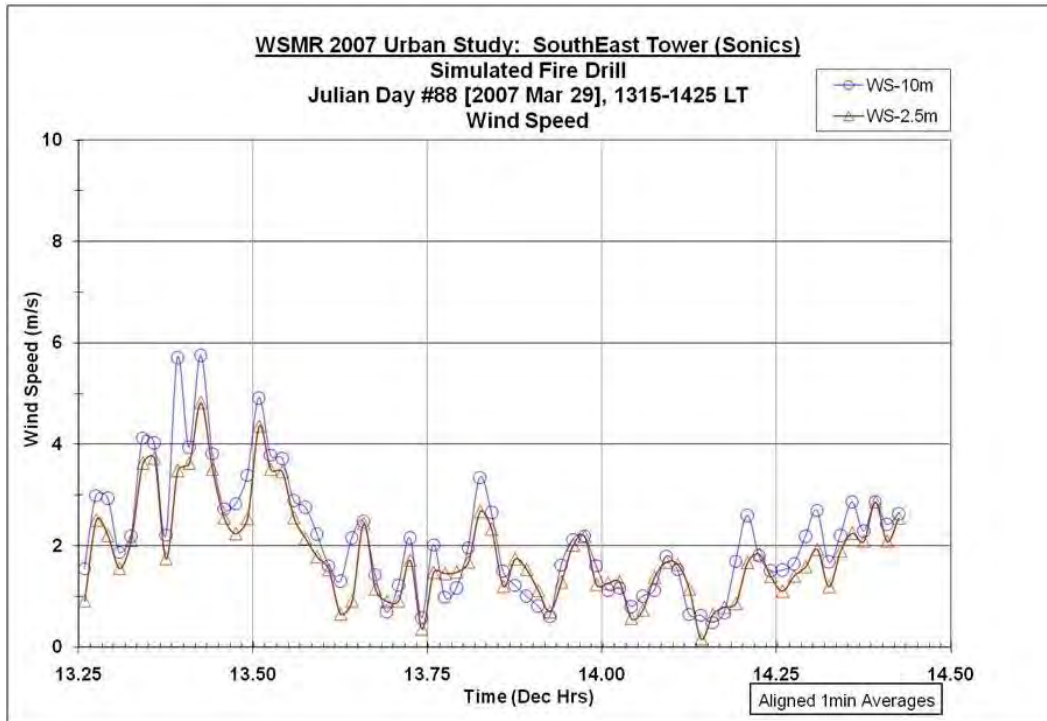


Figure C-11. SE tower (Sonics): Fire Drill Period–WS (March 29)

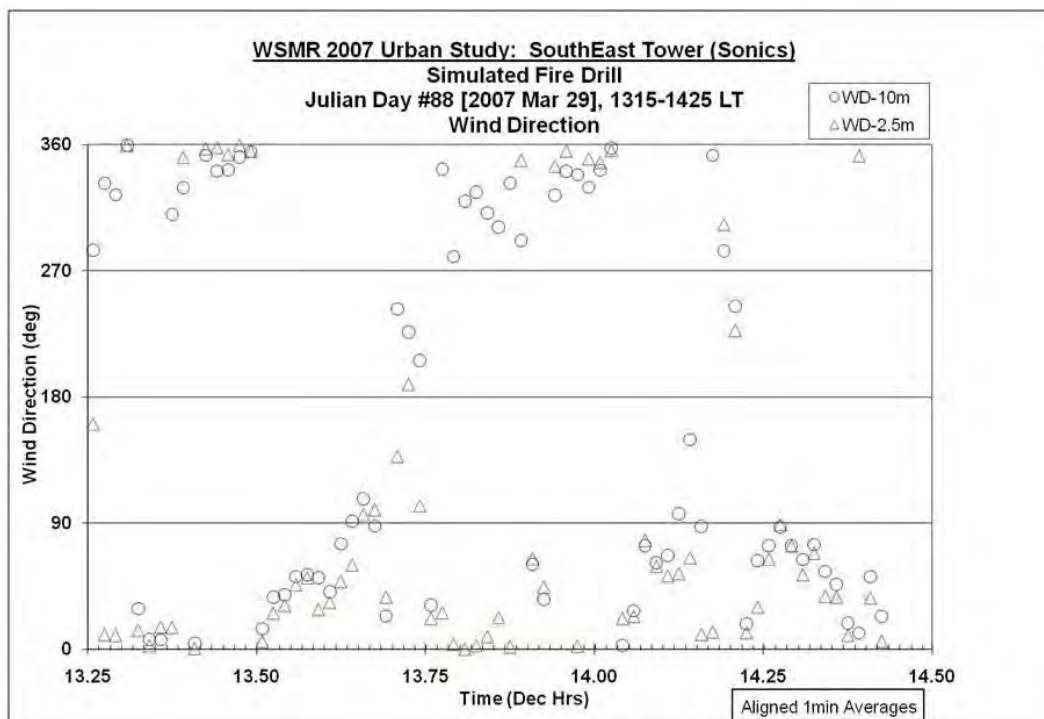


Figure C-12. SE tower (Sonics): Fire Drill Period–WD (March 29).

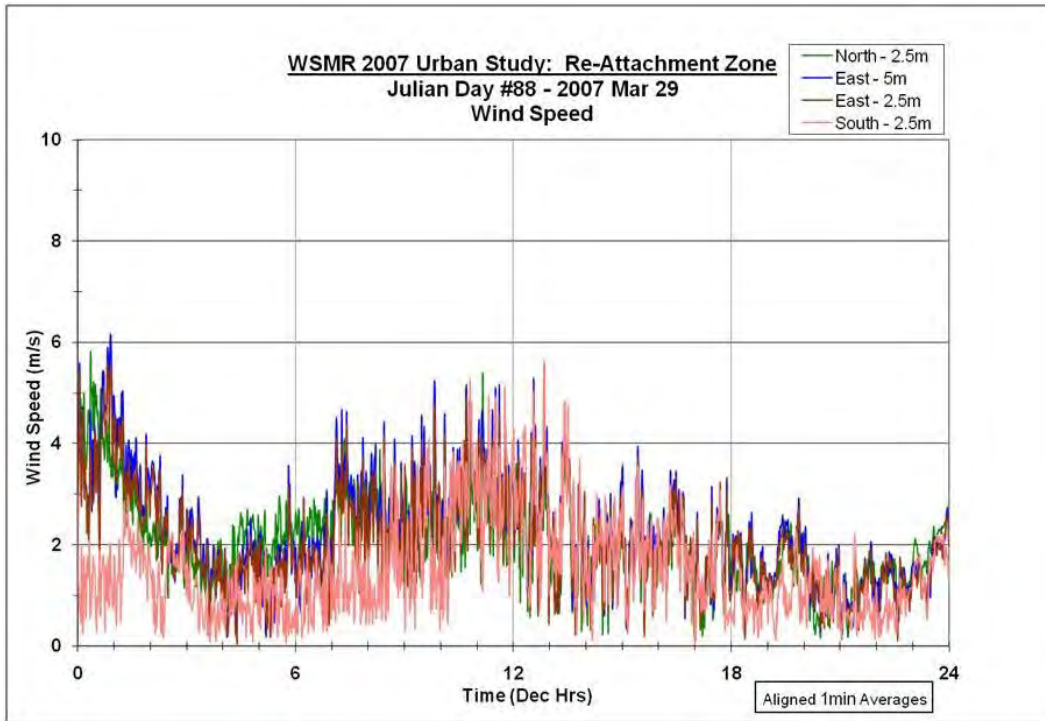


Figure C-13. RAZ tripods: WS (March 29).

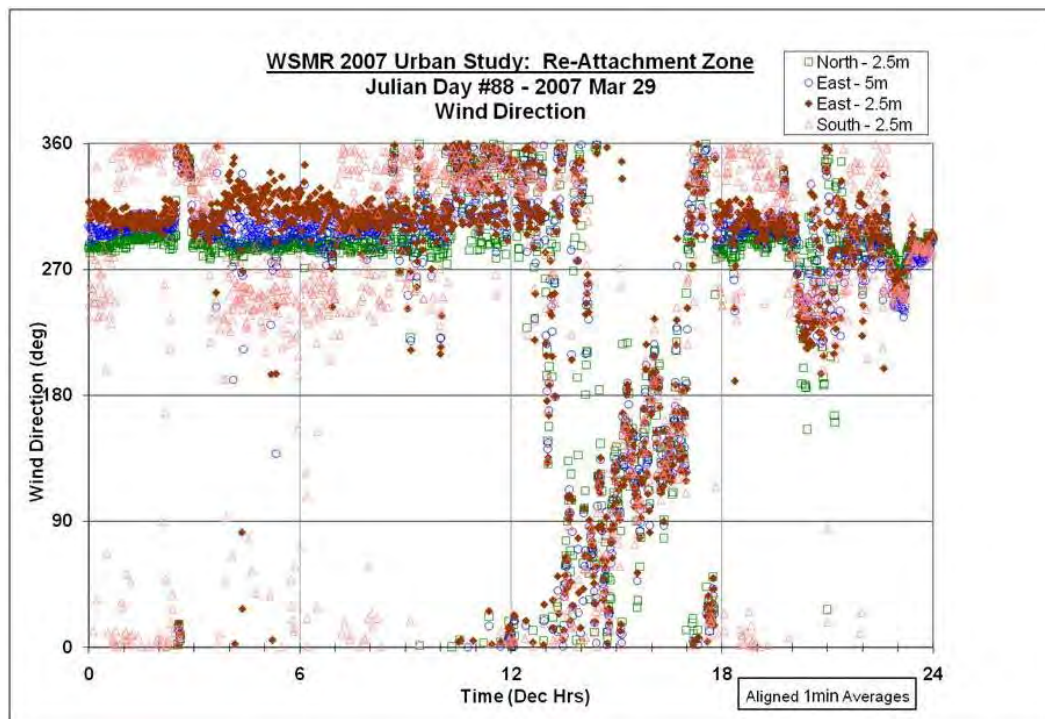


Figure C-14. RAZ tripods: WD (March 29).

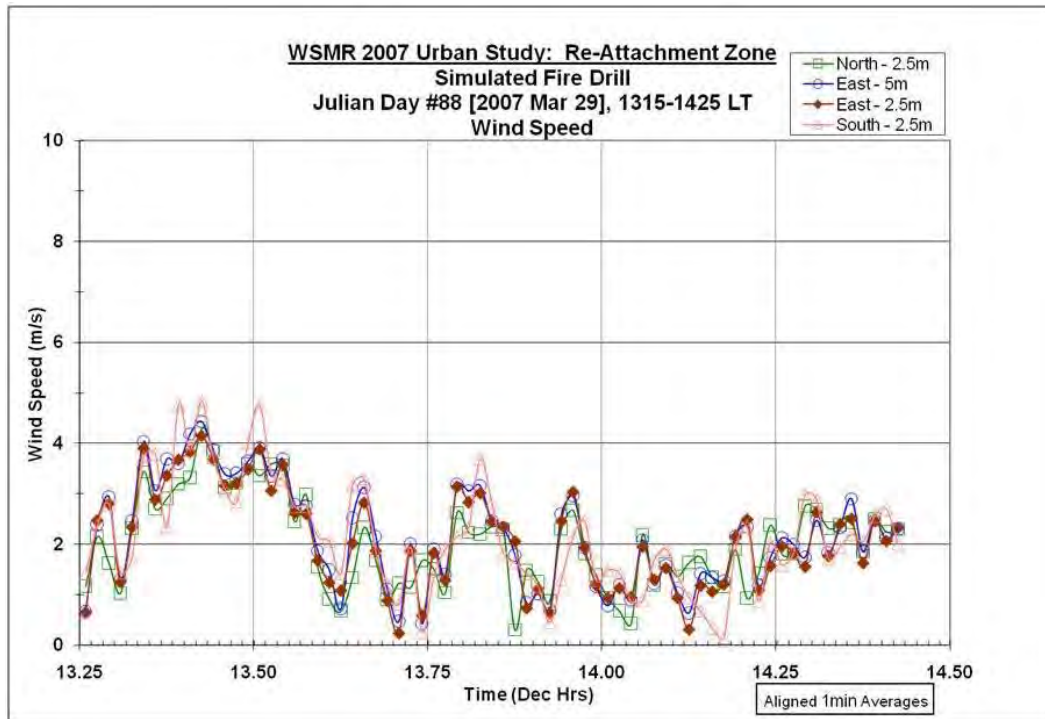


Figure C-15. RAZ tripods: Fire Drill Period–WS (March 29).

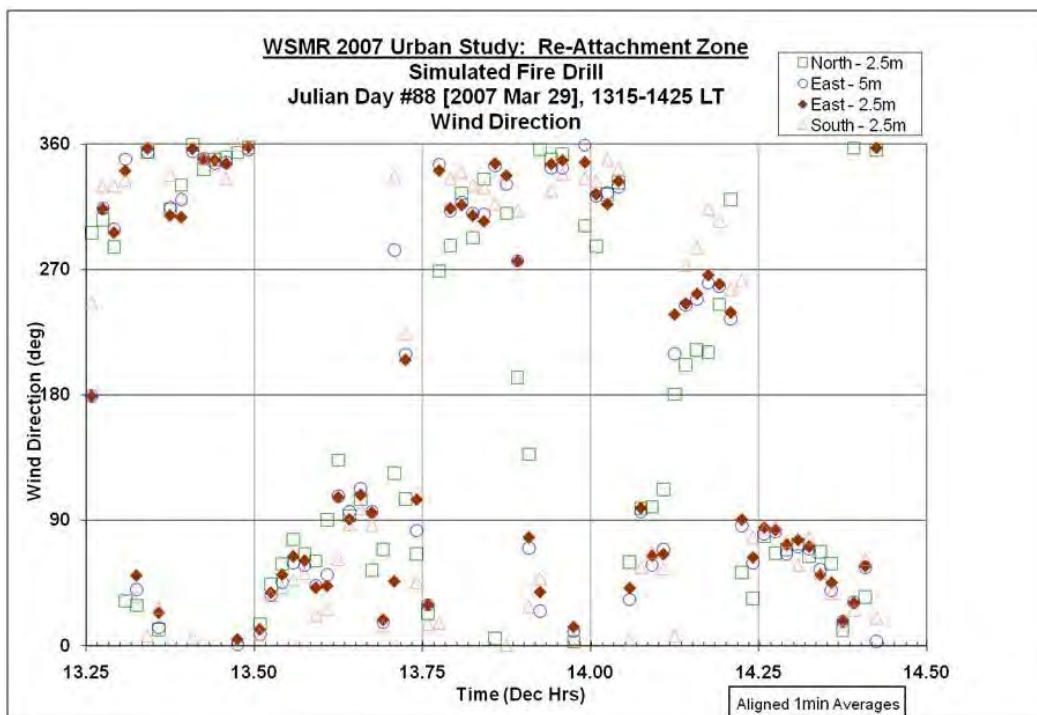


Figure C-16. RAZ tripods: Fire Drill Period–WD (March 29).

## C-2 W07US Dynamic Data, 2007 March 30 (JD# 89)–Simulated Bomb Threat Drill

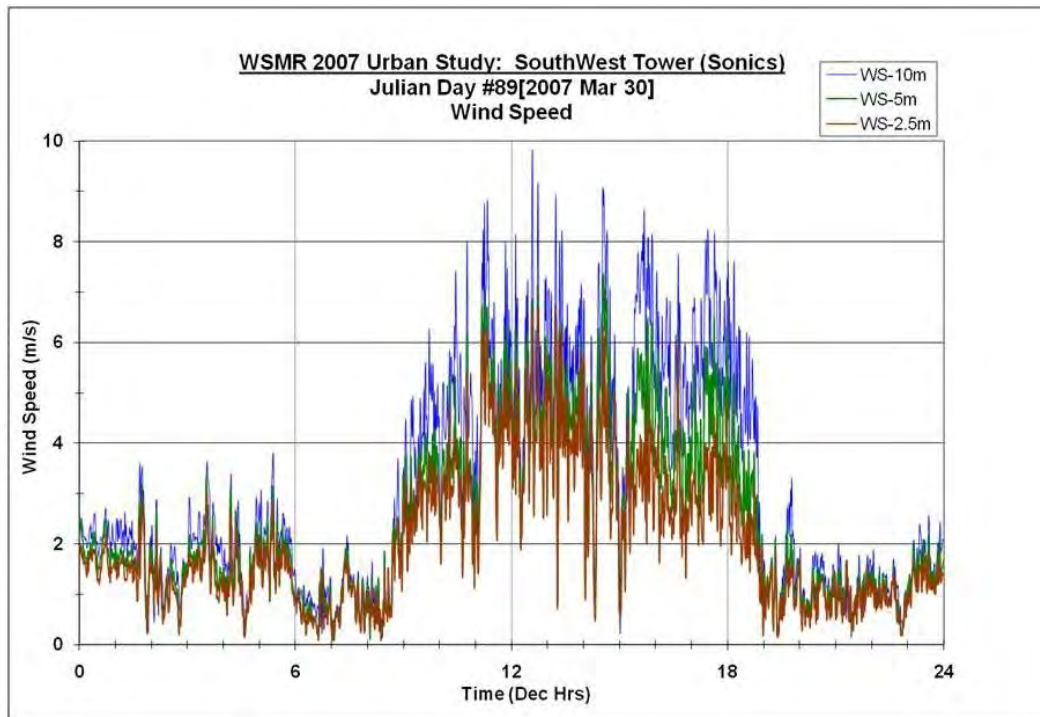


Figure C-17. SW tower (Sonics): WS (March 30).

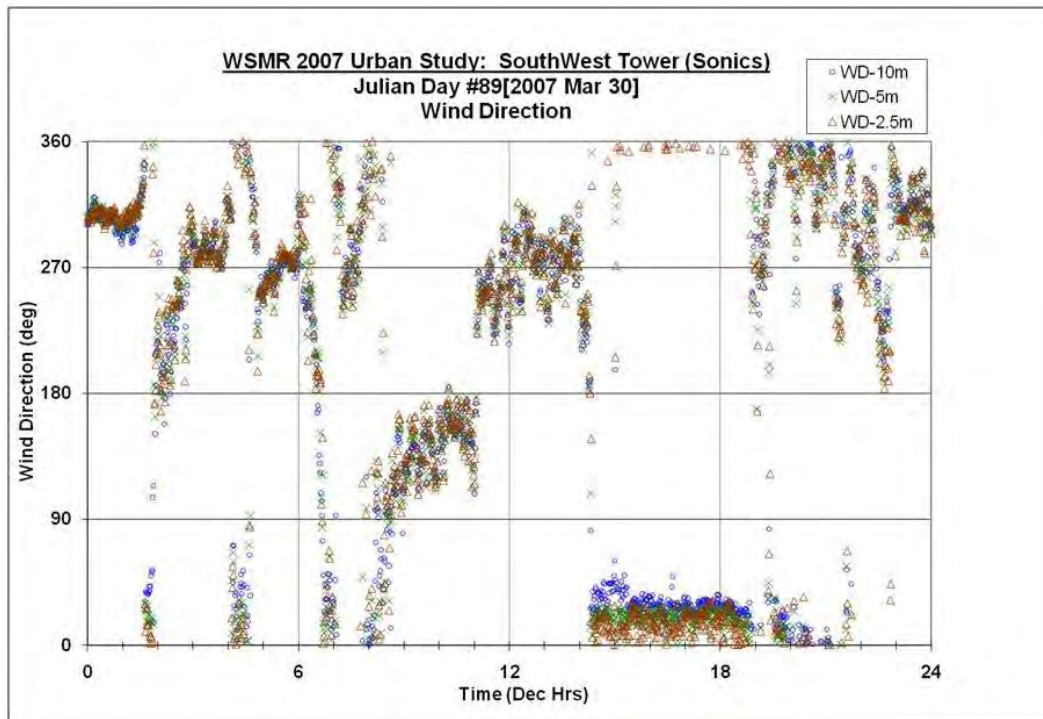


Figure C-18. SW tower (Sonics): WD (March 30).



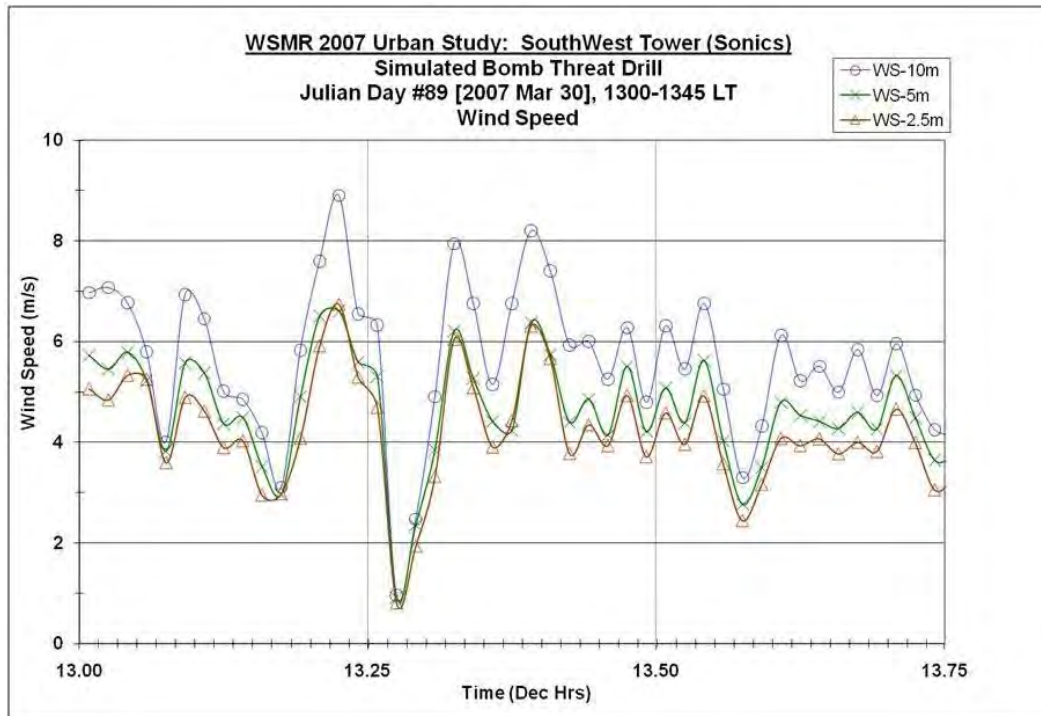


Figure C-19. SW tower (Sonics): Simulated bomb threat drill period–WS (March 30).

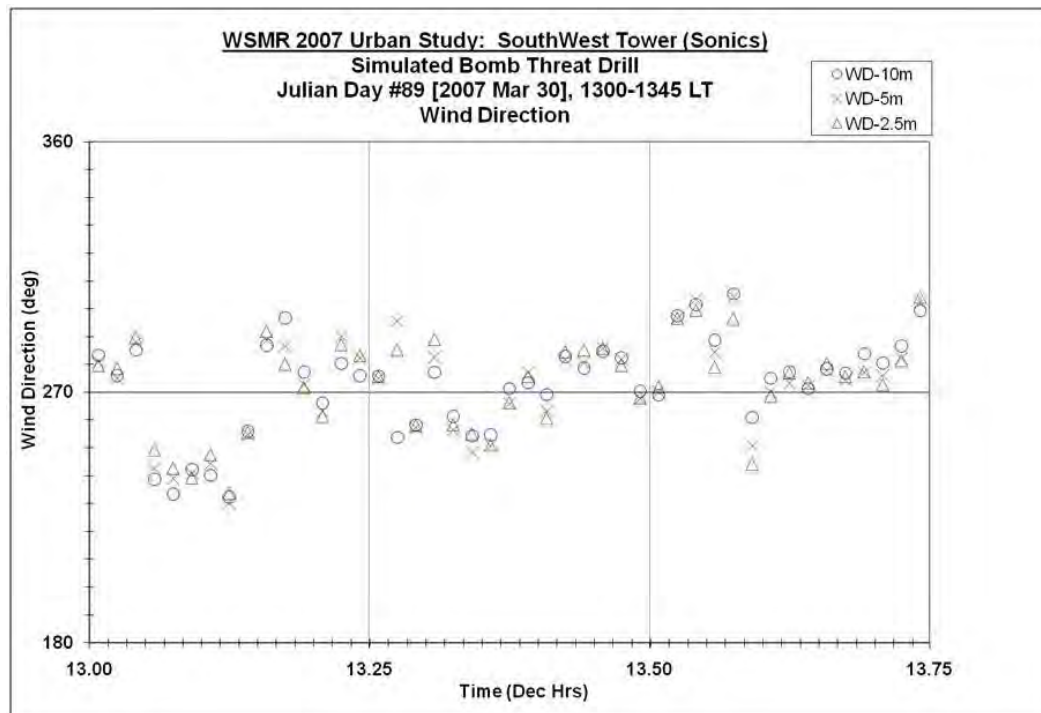


Figure C-20. SW tower (Sonics): Simulated bomb threat drill period–WD (March 30).

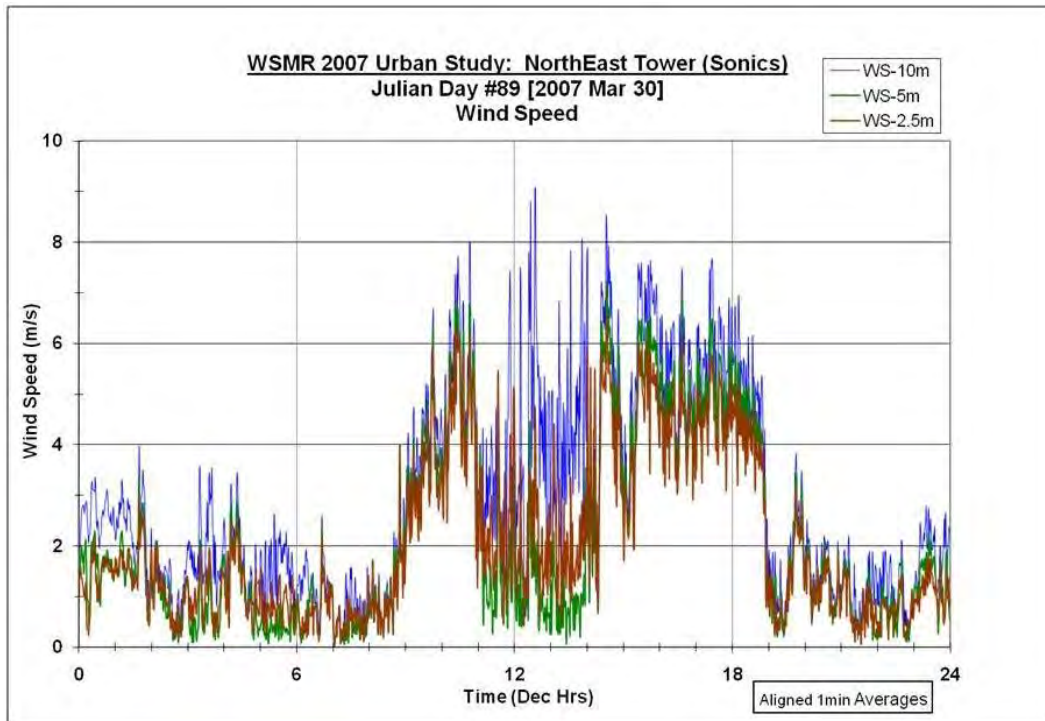


Figure C-21. NE tower (Sonics): WS (March 30).

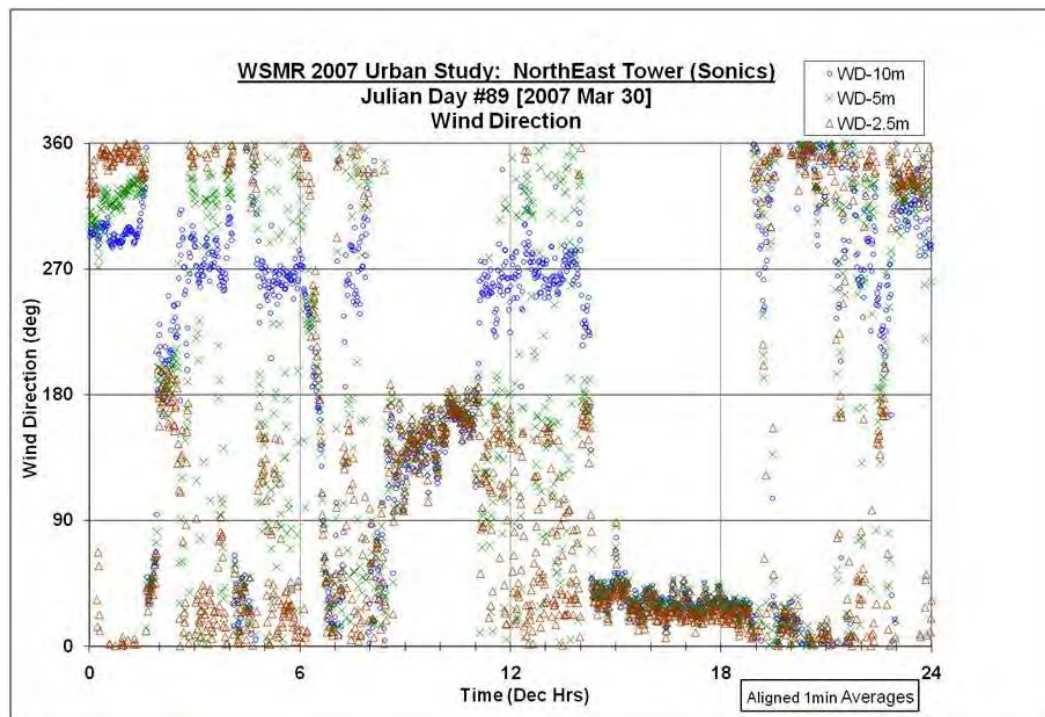


Figure C-22. NE tower (Sonics): WD (March 30).

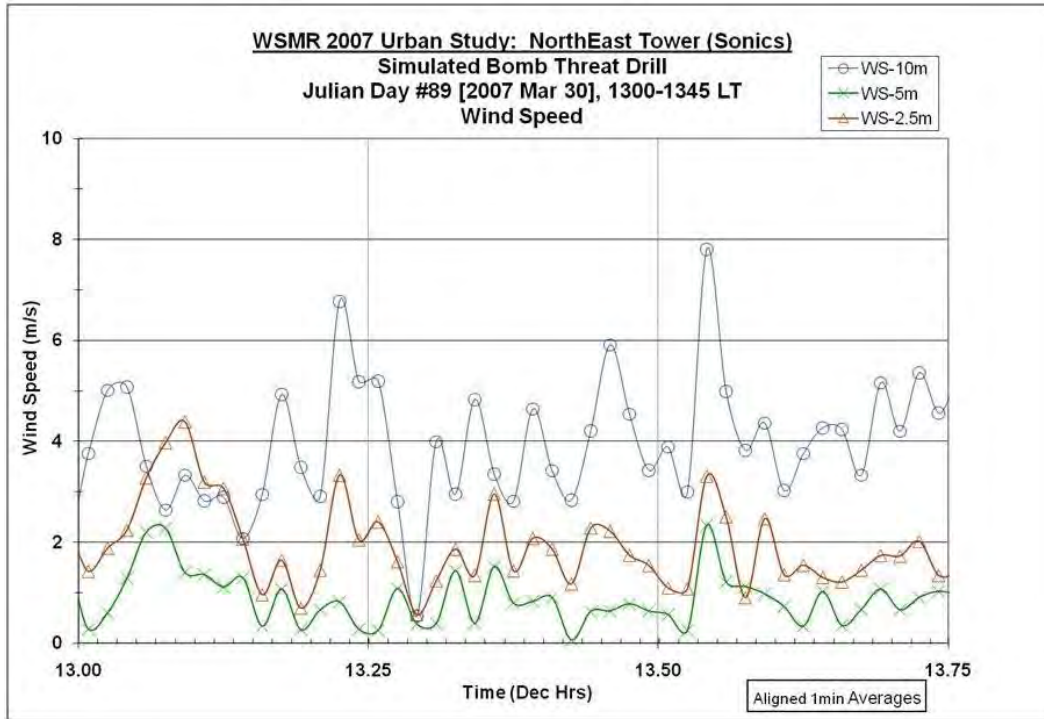


Figure C-23. NE tower (Sonics): Simulated bomb threat drill period–WS (March 30).

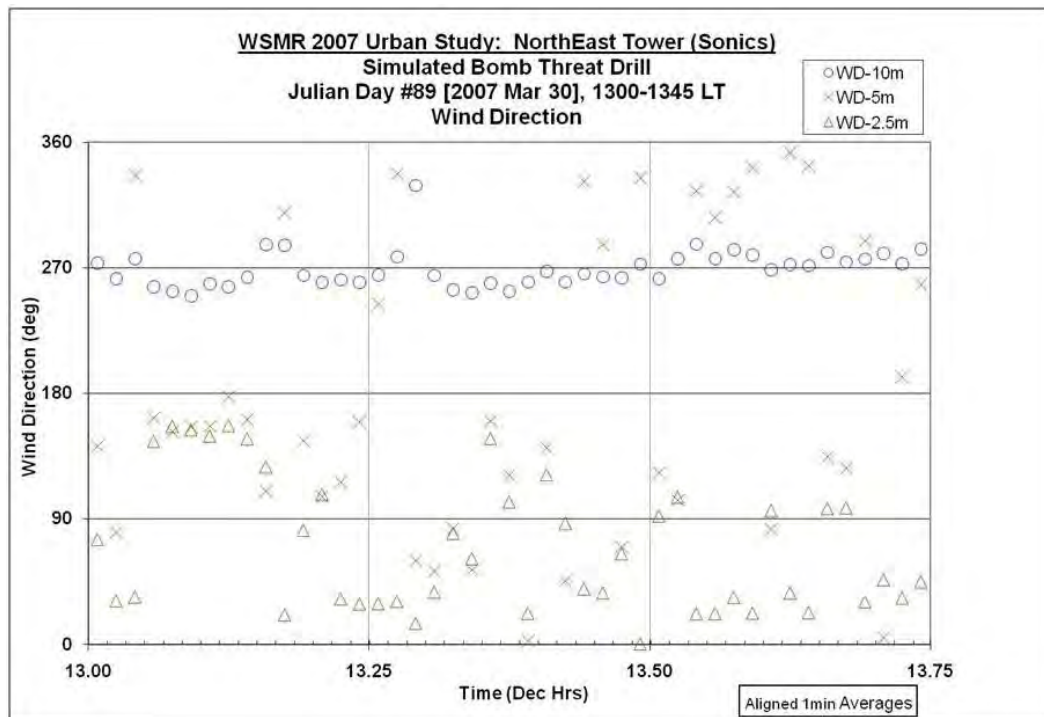


Figure C-24. NE tower (Sonics): Simulated bomb threat drill period–WD (March 30).



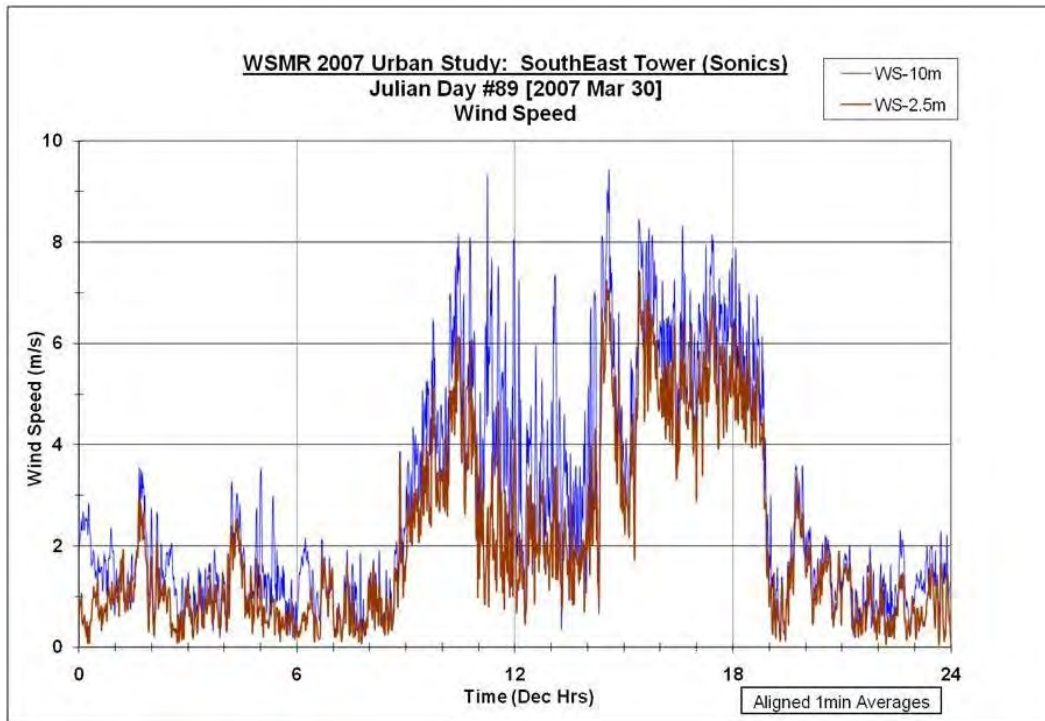


Figure C-25. SE tower (Sonics): WS (March 30).

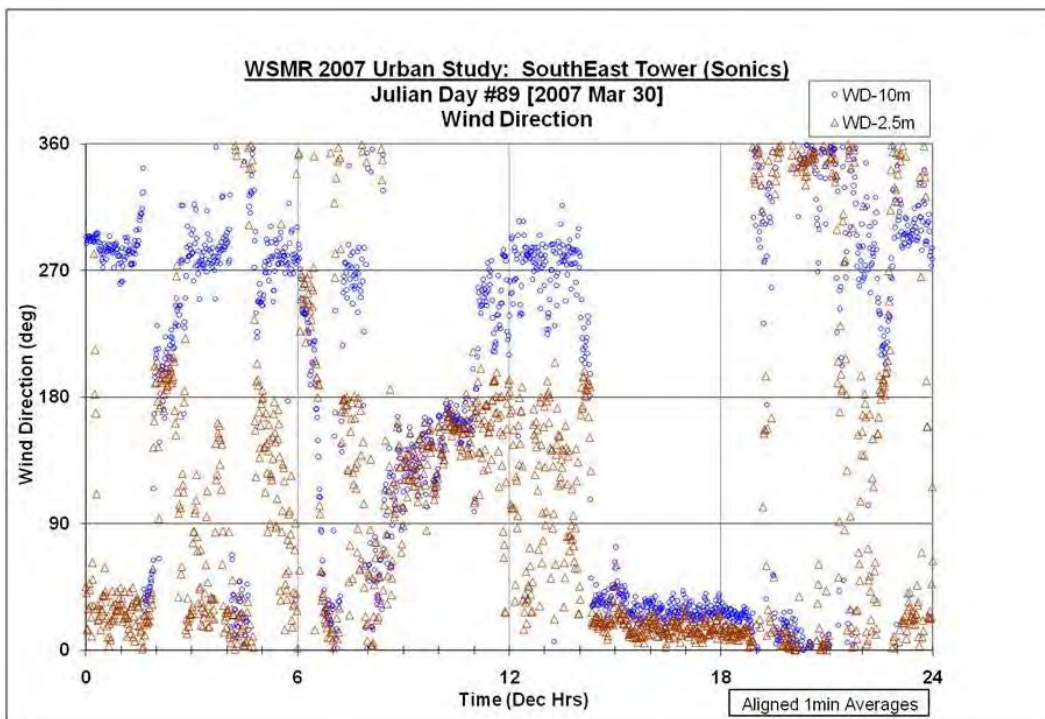


Figure C-26. SE tower (Sonics): WD (March 30).

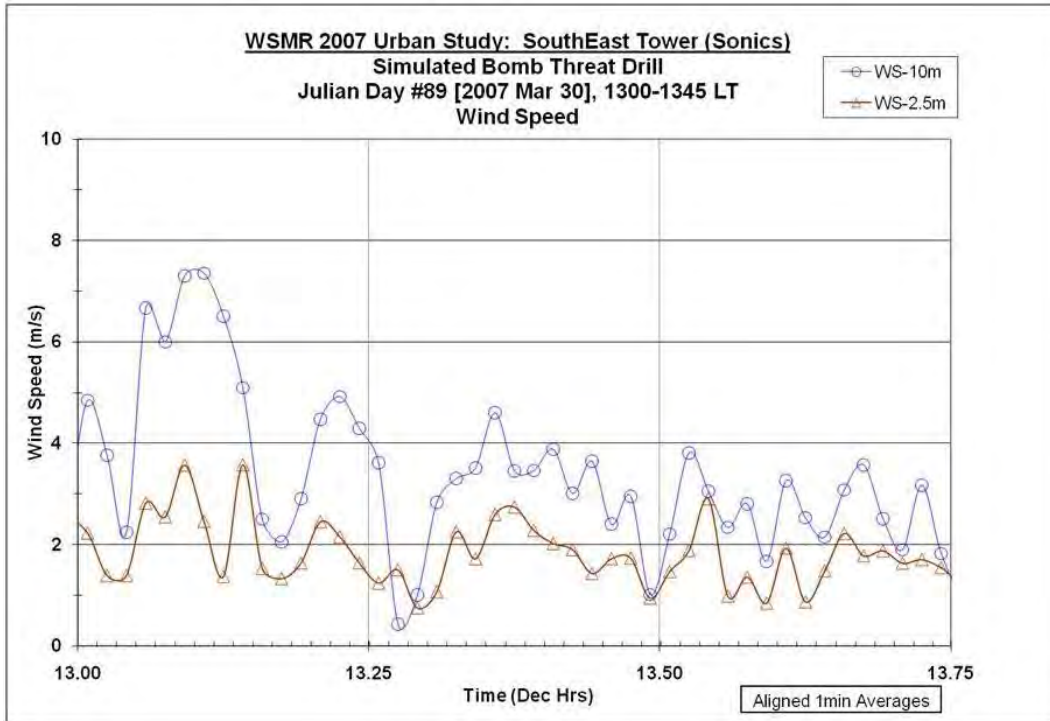


Figure C-27. SE tower (Sonics): Simulated bomb threat drill period–WS (March 30).

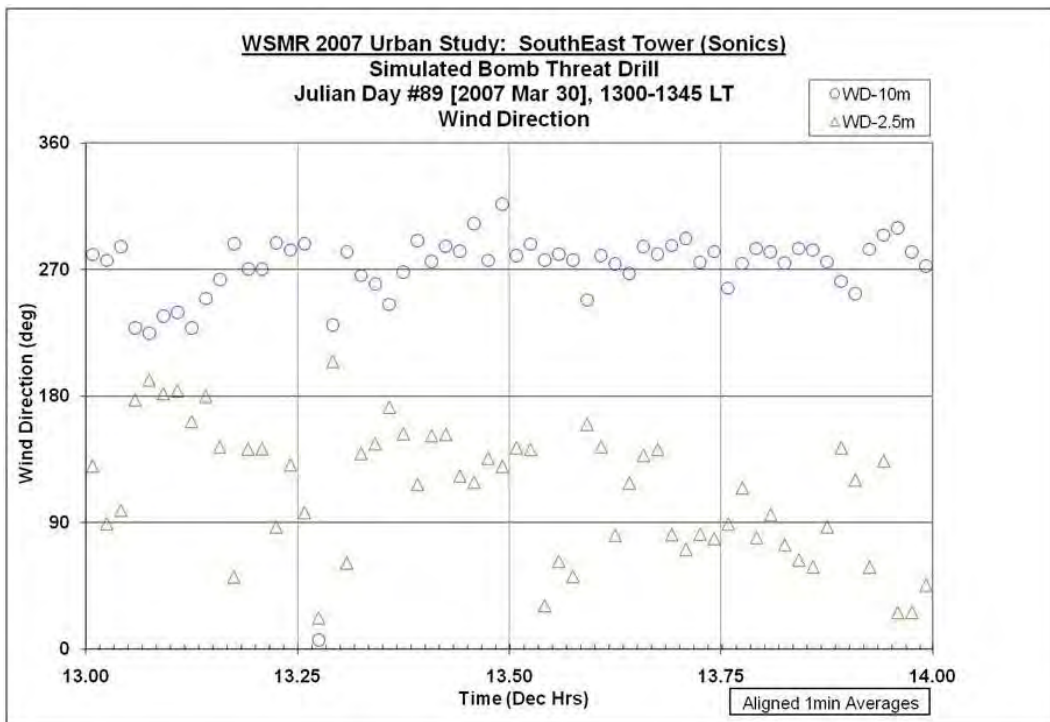


Figure C-28. SE tower (Sonics): Simulated bomb threat drill period–WD (March 30).

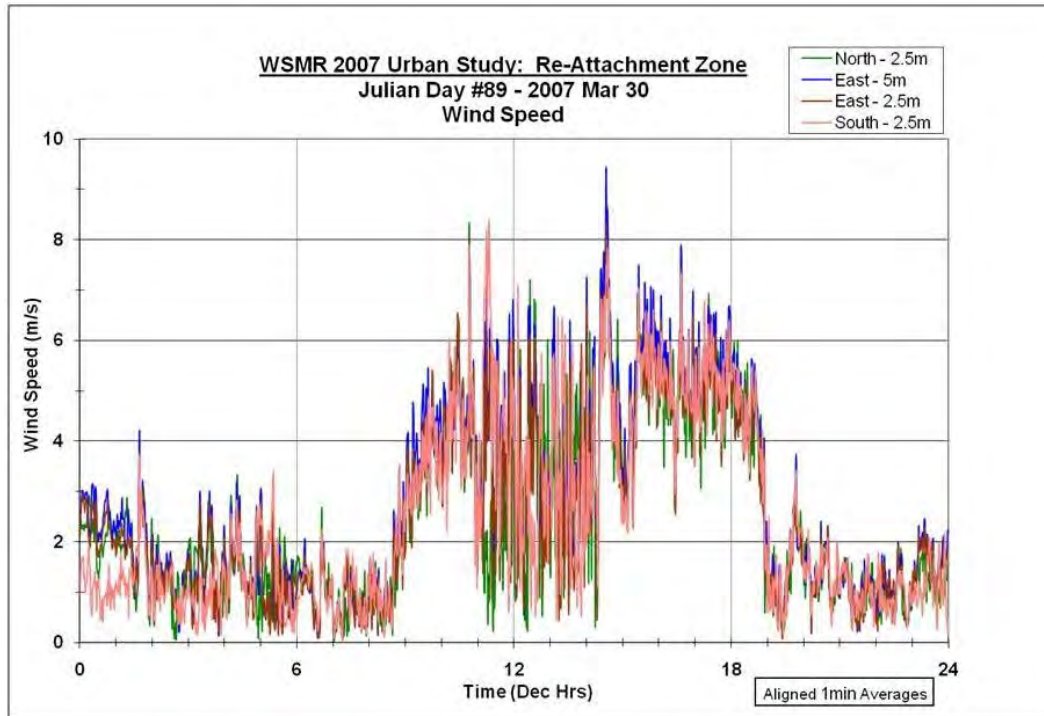


Figure C-29. RAZ tripods: WS (March 30).

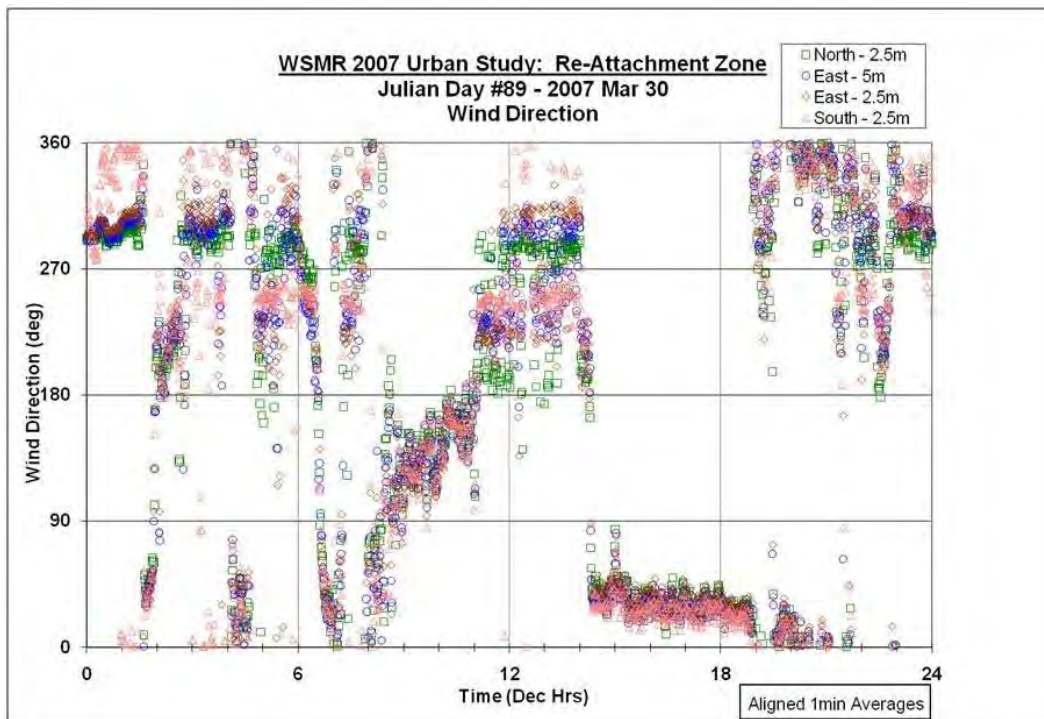


Figure C-30. RAZ tripods: WD (March 30).



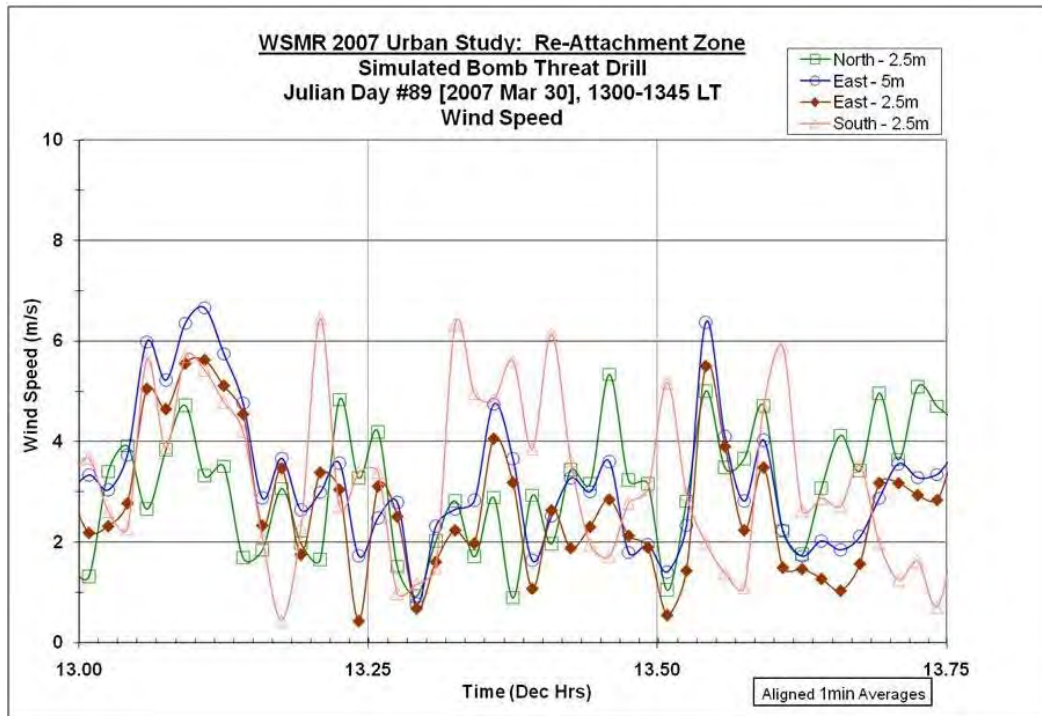


Figure C-31. RAZ tripods: Simulated bomb threat drill period I-WS (March 30)

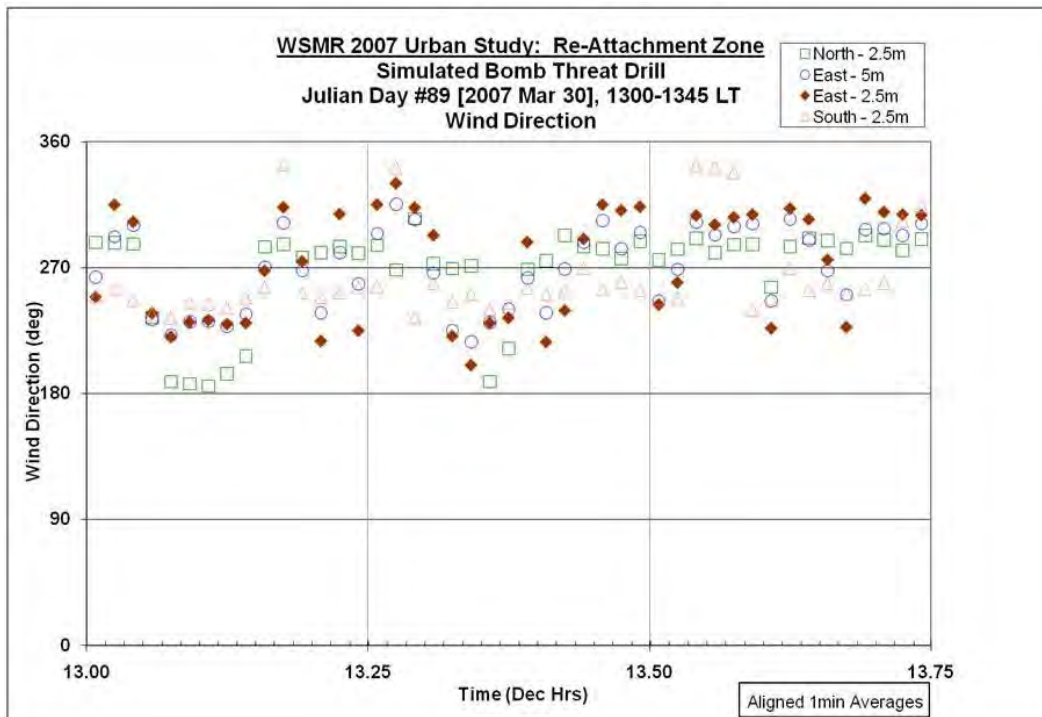


Figure C-32. RAZ tripods: Simulated bomb threat drill period-WD (March 30)

**C-3 W07US Dynamic Data, 2007 April 02 (JD# 92)–Simulated Airborne Chemical Release Drill**

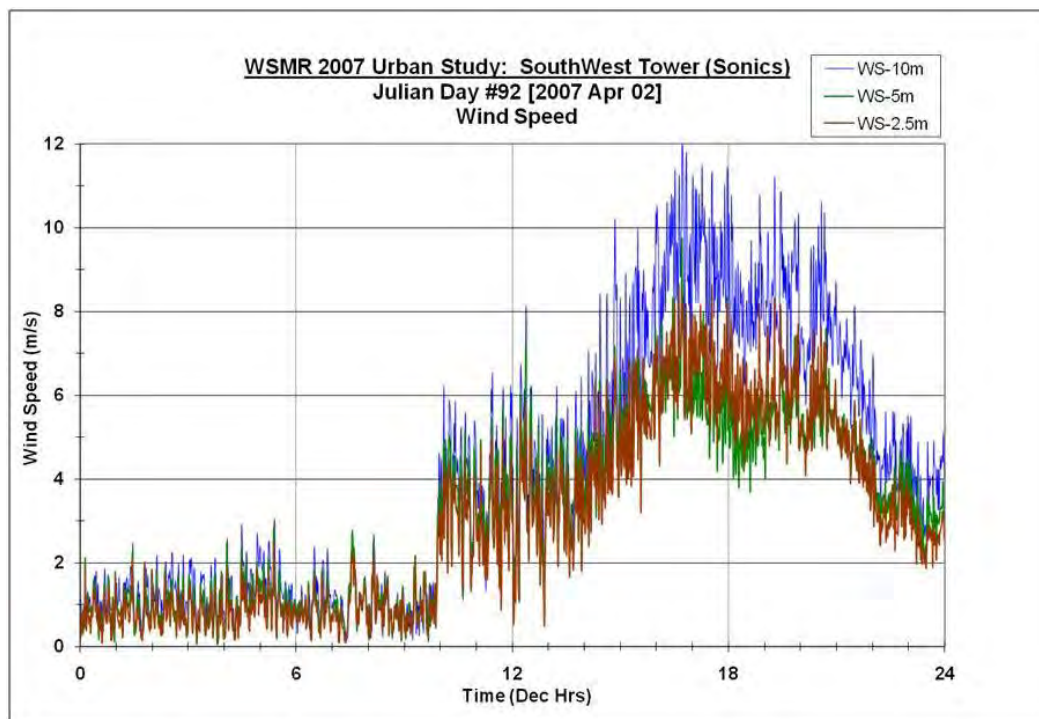


Figure C-33. SW tower (Sonics): WS (April 02).

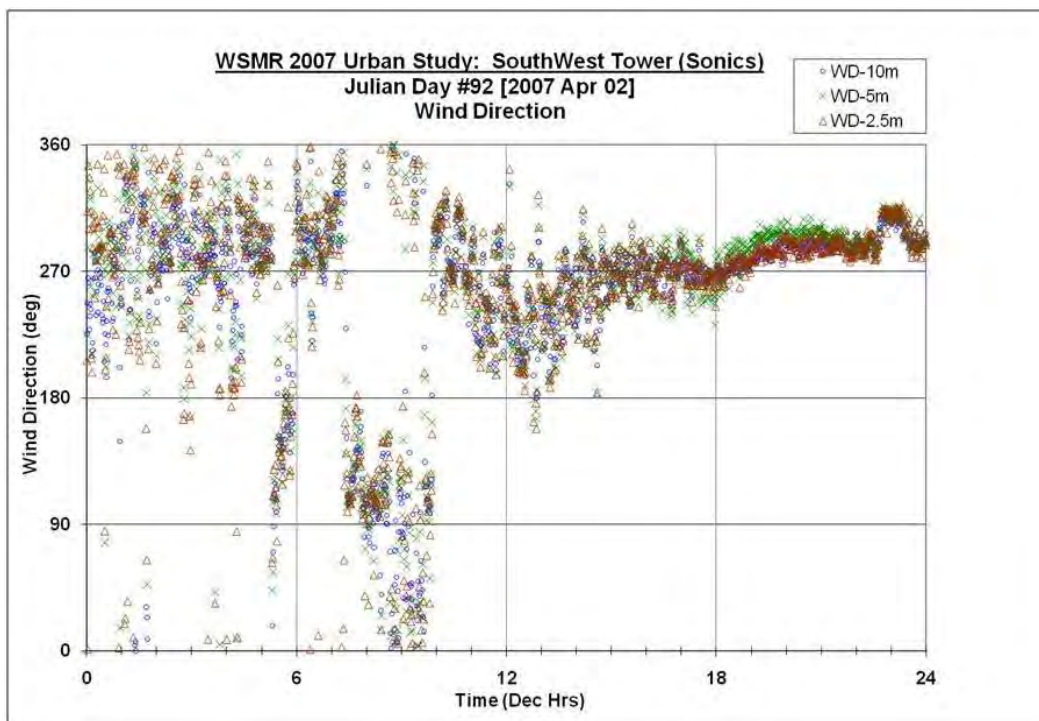


Figure C-34. SW tower (Sonics): WD (April 02).



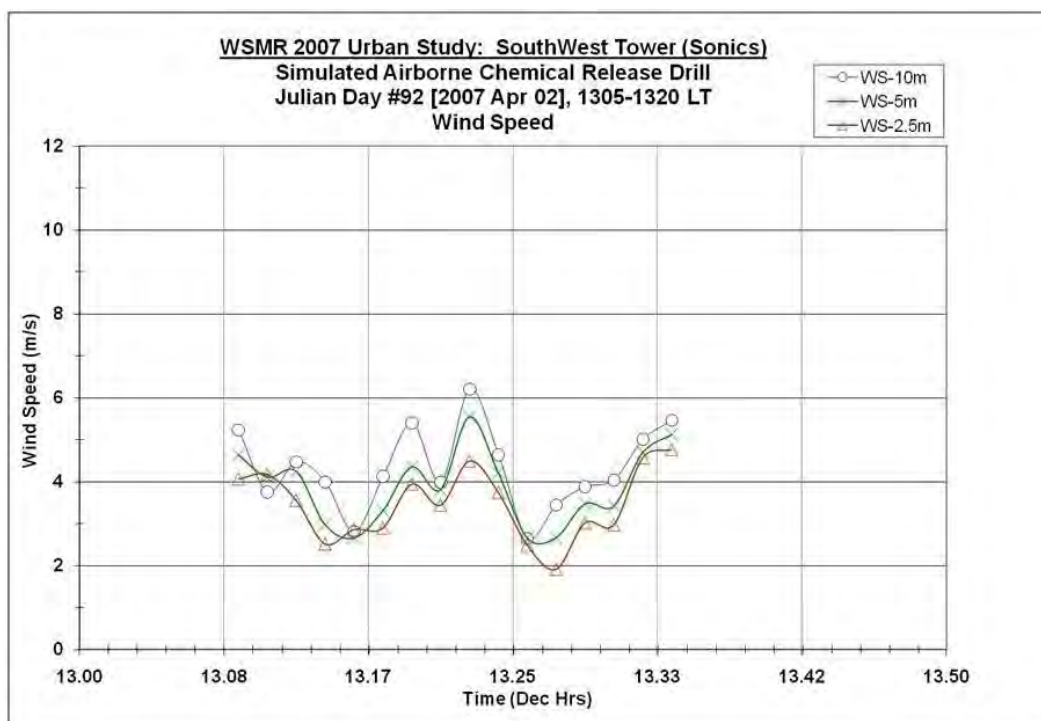


Figure C-35. SW tower (Sonics): Simulated airborne chemical release drill period–WS (April 02).

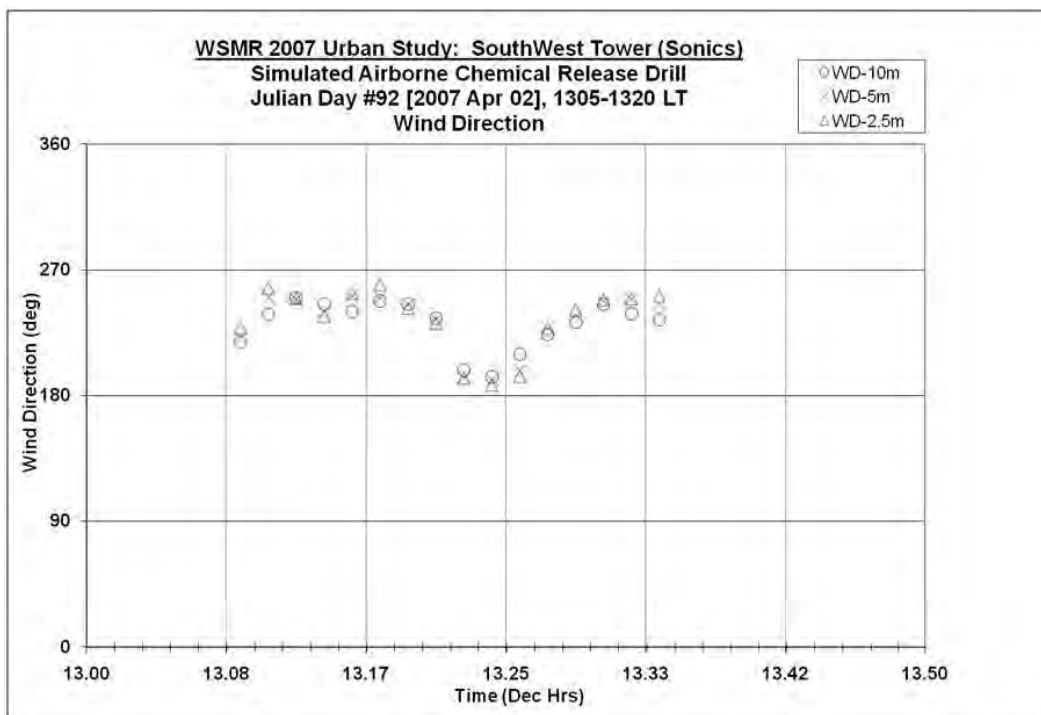


Figure C-36. SW tower (Sonics): Simulated airborne chemical release drill period–WD (April 02).

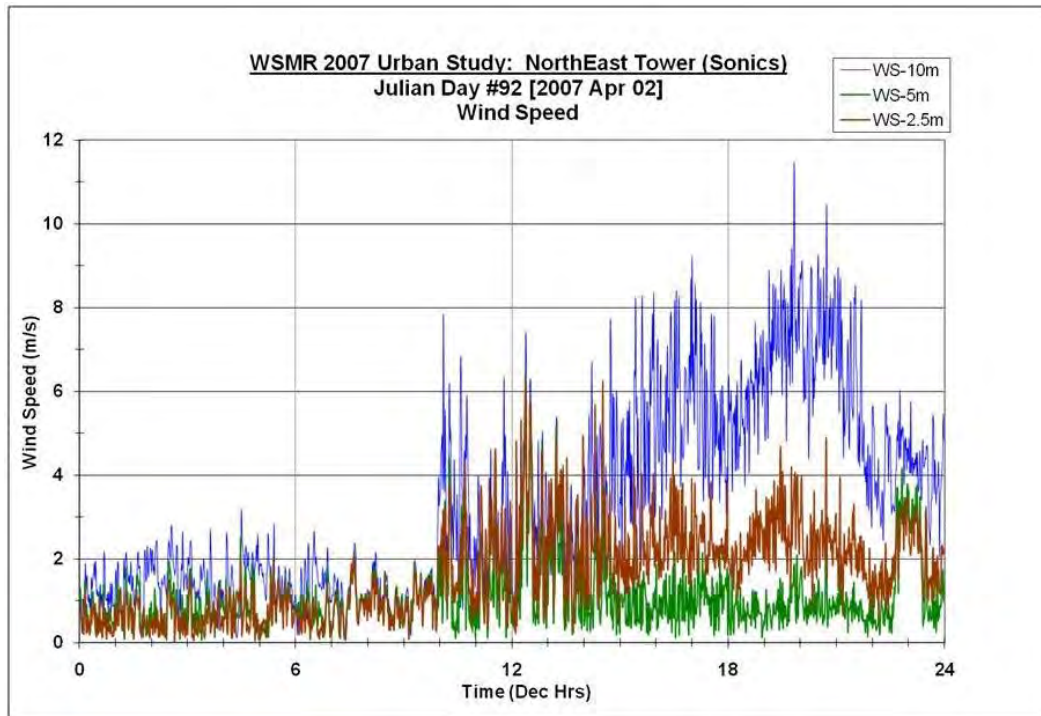


Figure C-37. NE tower (Sonics): WS (April 02).

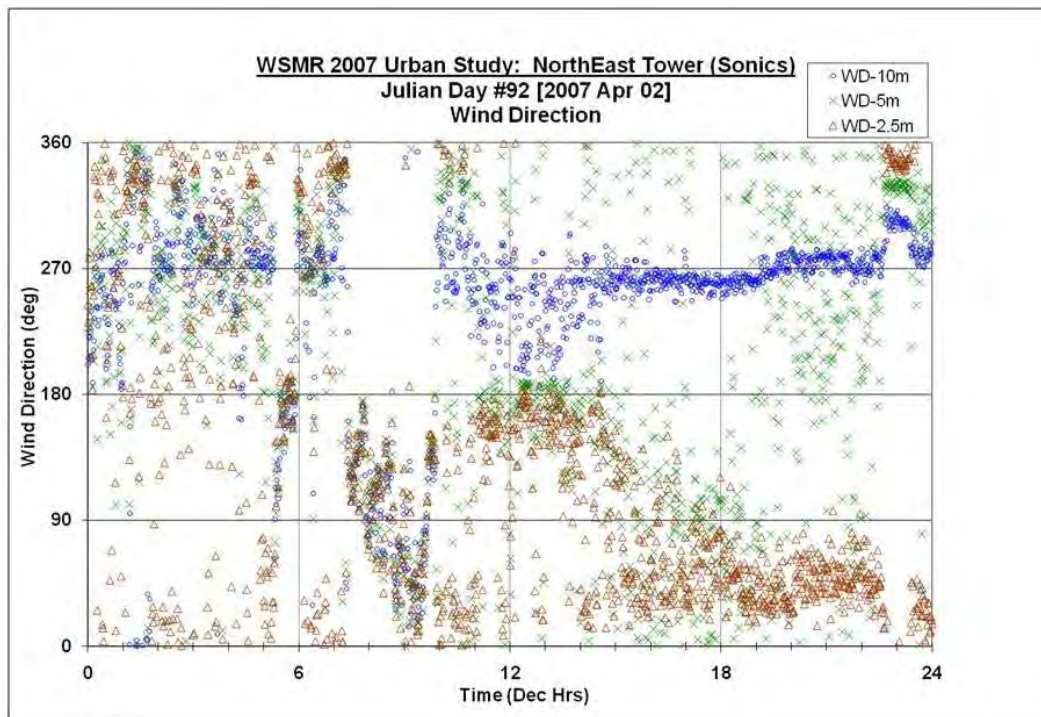


Figure C-38. NE tower (Sonics): WD (April 02).

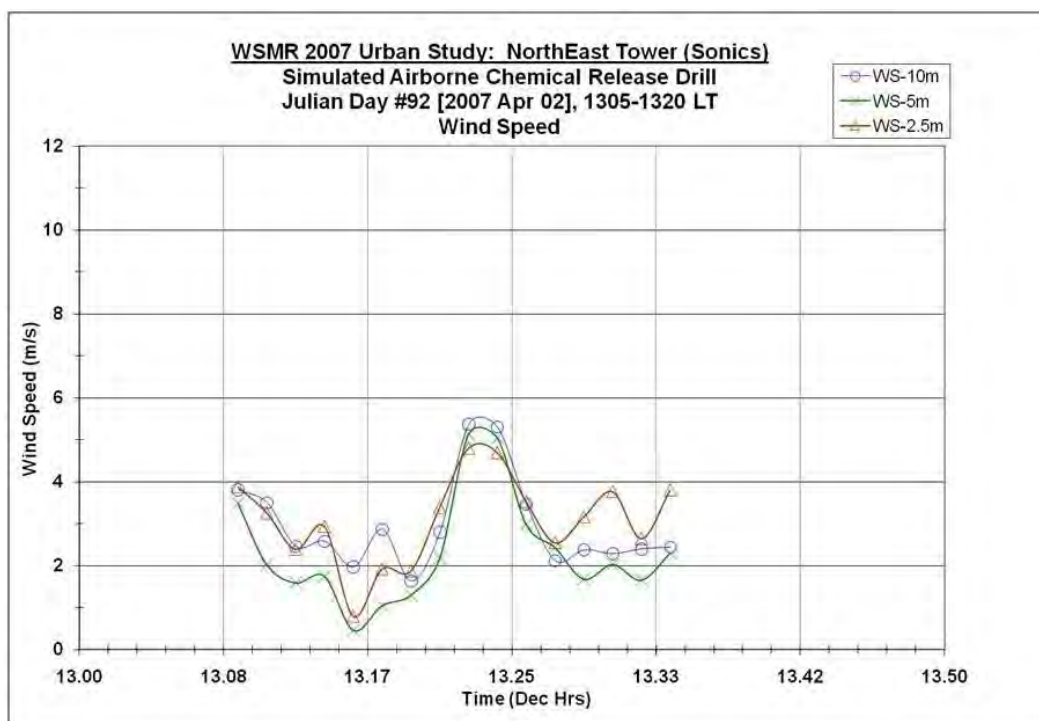


Figure C-39. NE tower (Sonics): Simulated airborne chemical release drill period–WS (April 02).

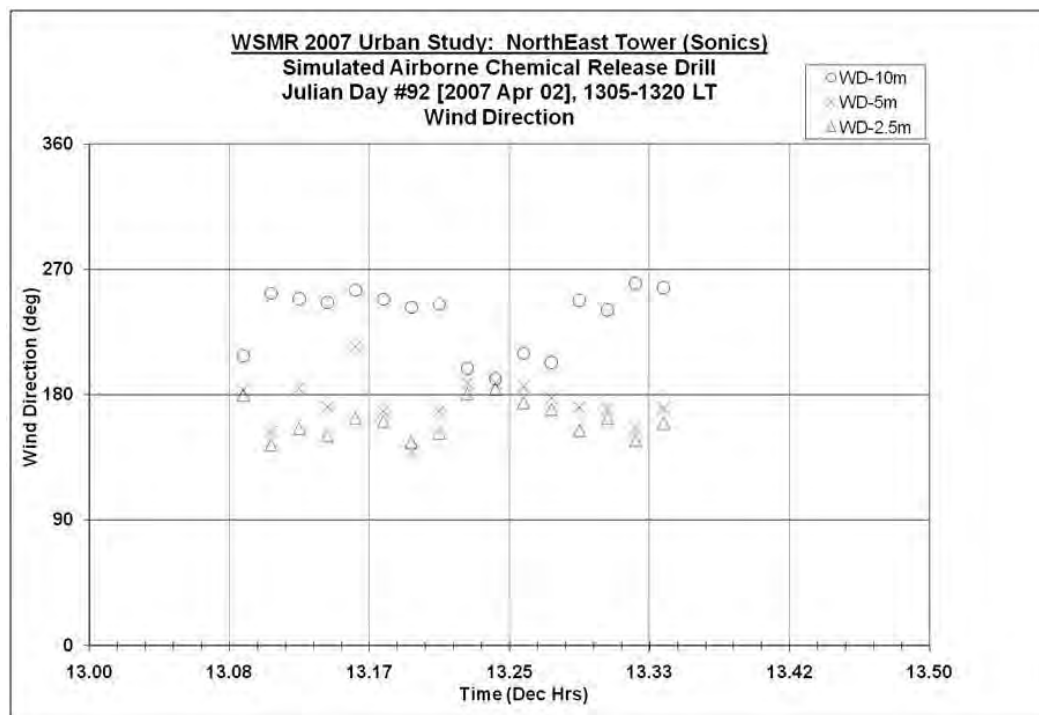


Figure C-40. NE tower (Sonics): Simulated airborne chemical release drill period–WD (April 02).

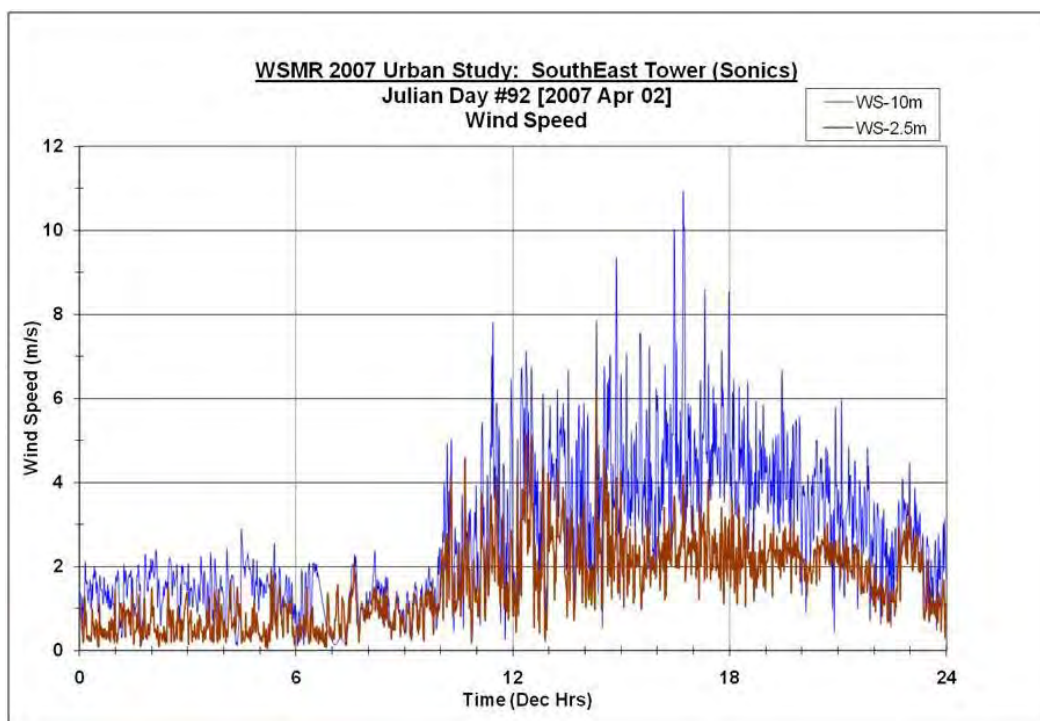


Figure C-41. SE tower (Sonics): WS (April 02).

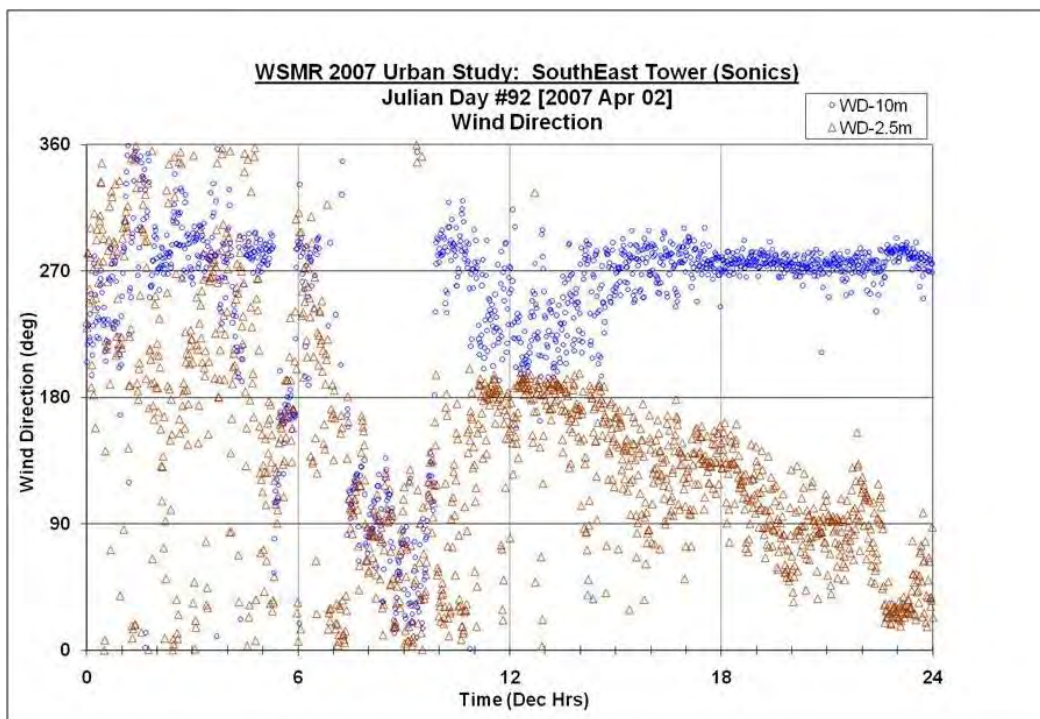


Figure C-42. SE tower (Sonics): WD (April 02).



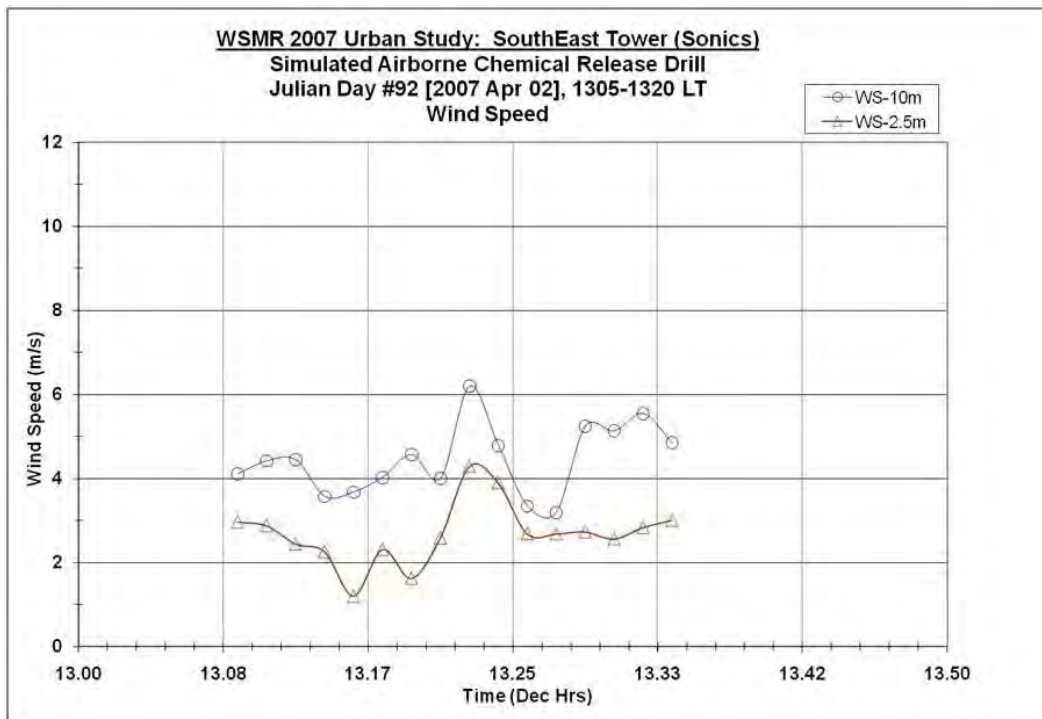


Figure C-43. SE tower (Sonics): Simulated airborne chemical release drill period–WS (April 02).

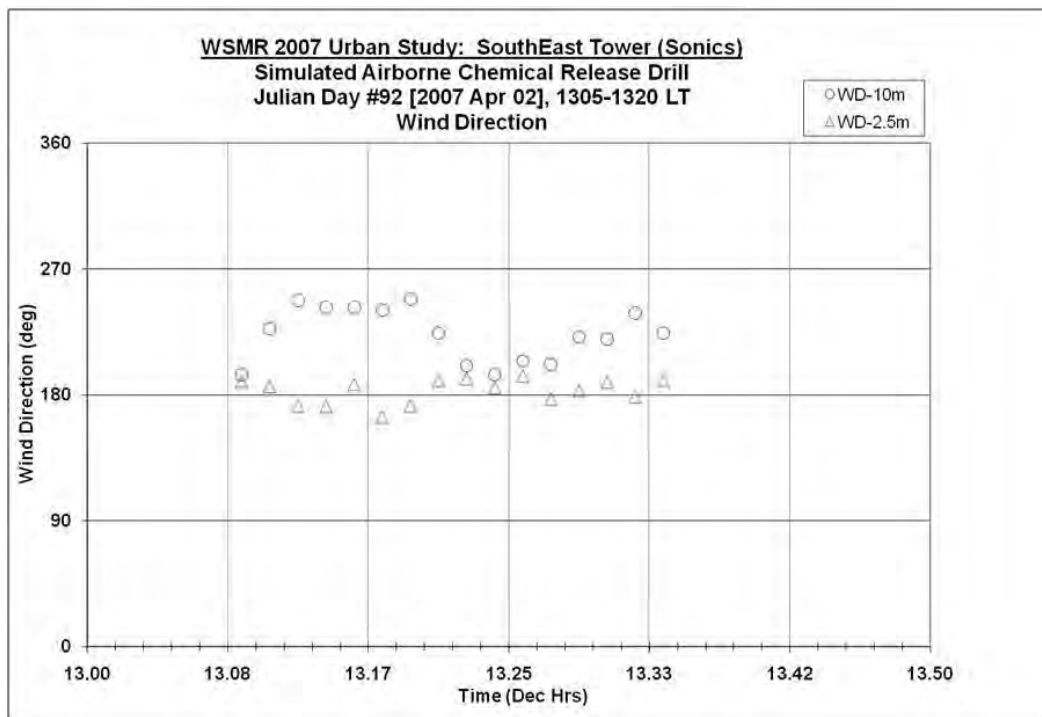


Figure C-44. SE tower (Sonics): Simulated airborne chemical release drill period–WD (April 02).

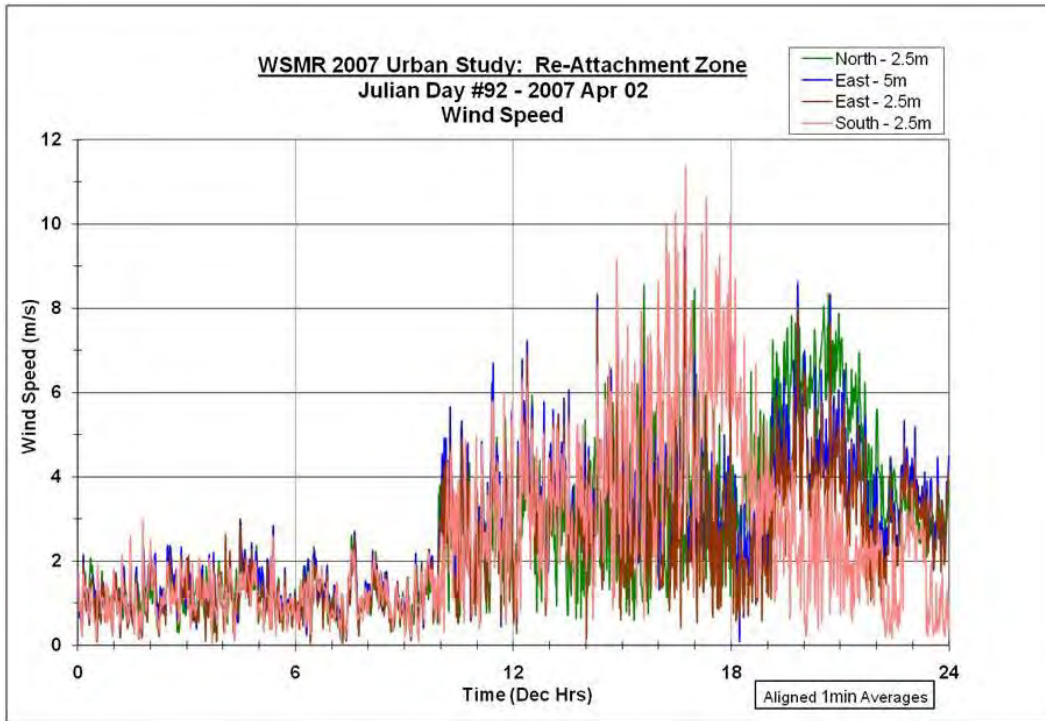


Figure C-45. RAZ: WS (April 02).

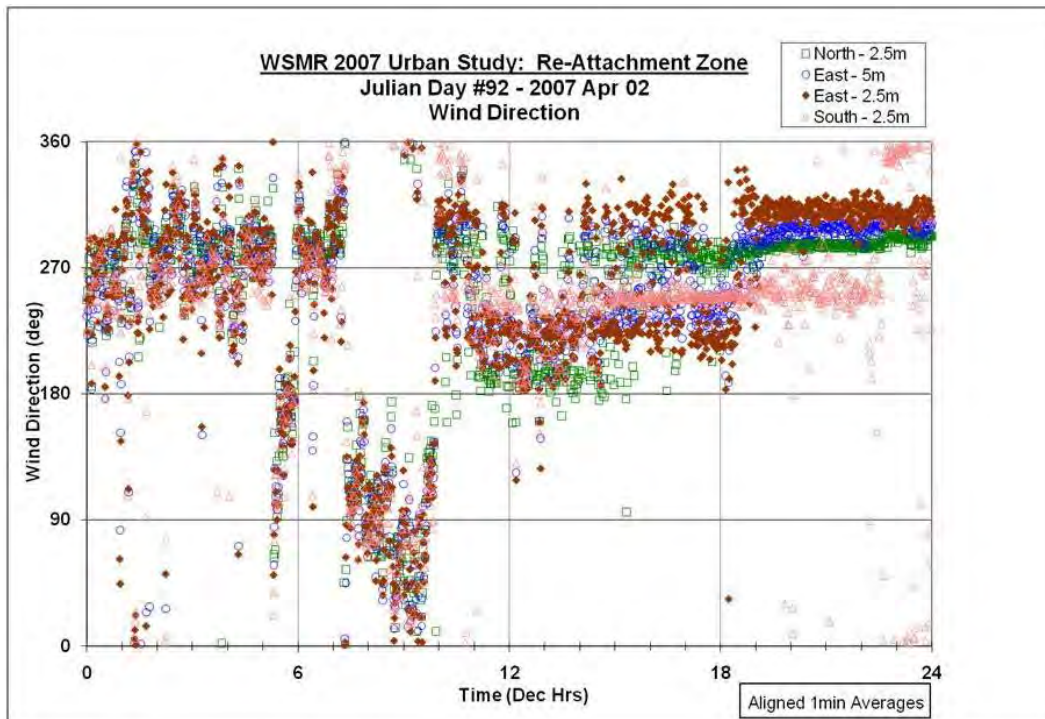


Figure C-46. RAZ: WD (April 02).



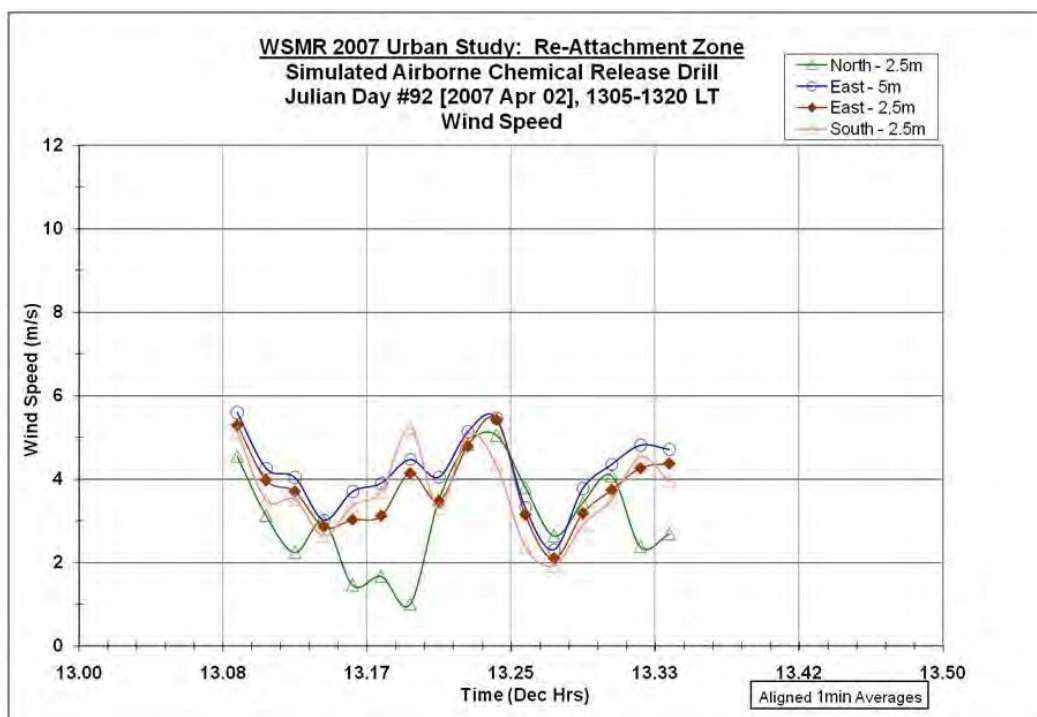


Figure C-47. RAZ: Simulated airborne chemical release drill period–WS (April 02).

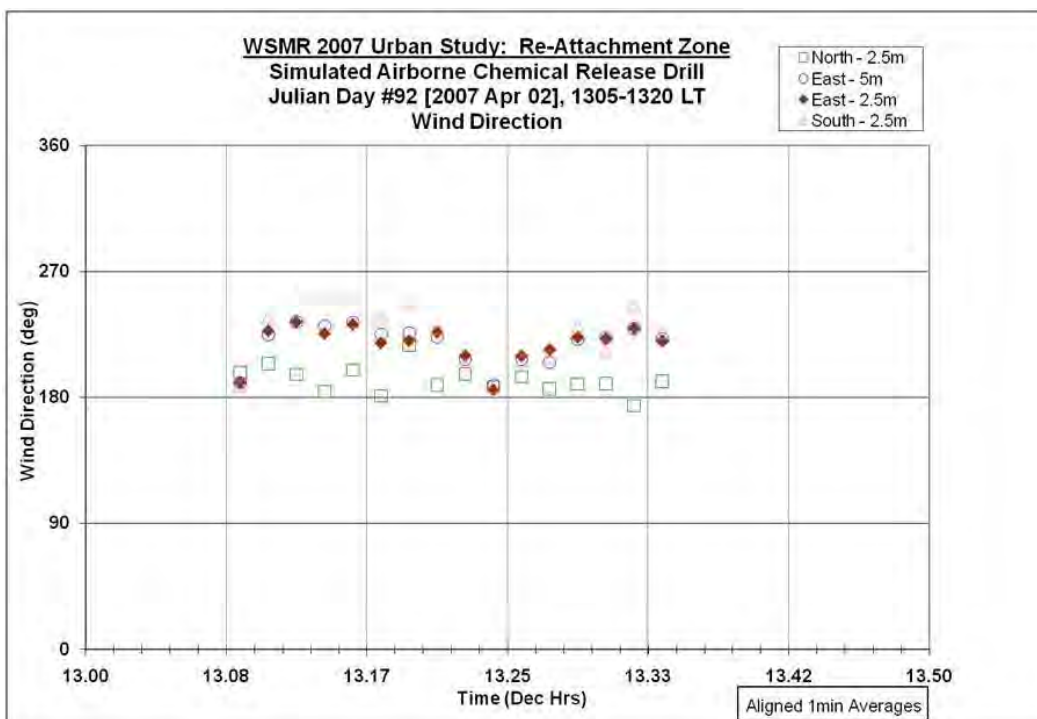


Figure C-48. RAZ: Simulated airborne chemical release drill period–WD (April 02).

INTENTIONALLY LEFT BLANK.

---

## **Appendix D. Model representation of the 2007 April 2, Simulated Chemical Airborne Release Drill.**

---

This appendix displays the wind and plume output simulating the 2007 April 2 Simulated Chemical Airborne Release Drill.

Figure D-1 shows the area of interest as discussed in section 5. The subject building is highlighted.

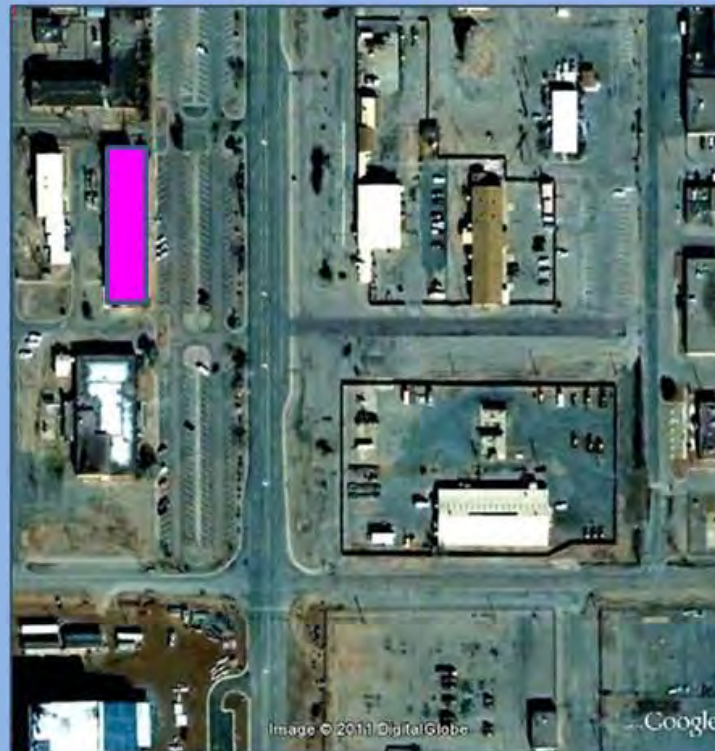
Figure D-2 presents the Chemical Threat description used in the ALOHA dispersion model.

Figures D-3 through D-18, show a one-minute representation of a 16 minute sequence of both wind flow and simulated chemical release footprints. The diagnostic wind model used was 3DWF-version 2. The plume model used was the ALOHA-Heavy Gas Model. The three threat zones were based on standard LOC gradients. Each gradient represents a threshold of hazard to the human body. For this case, concentrations of <0.5 ppm mapped the area where health effects were not disabling and were reversible upon cessation of exposure (AEGL-1, yellow line). The irreversible, long lasting adverse effects leading to an impaired ability to escape were contained in areas >0.5 ppm, and <2 ppm concentrations (AEGL-2, orange line). Concentrations of >20 ppm represented health effects that were life-threatening or the cause of death (AEGL-3, red line). ALOHA also provided an uncertainty line around the longest threat zone. This perimeter line represented the region between which the gas cloud was expected to remain for about 95% of the time. Note that in ALOHA, the 60-min AEGL exposure limits are the default toxic LOC. In other words, the toxic gradients are considered valid for a maximum of 60 min.

Figure D-19 shows a wind and plume representation based on a 16-min averaged meteorological data input.

## Simulated Airborne Chemical Release Drill – 2007 April 2

Simulation Model: ALOHA/CAMEO/MARPLOT



**Area of Interest (AOI)**

Area of interest as discussed in section 5.4. The pink box identifies the subject building for this simulation.

Figure D-1. Area of interest as discussed in section 5. The pink box identifies the subject building for this simulation.

## Simulated Airborne Chemical Release Drill – 2007 April 2

### Simulation Model: ALOHA/CAMEO/MARPLOT

#### **SITE DATA:**

Location: WHITE SANDS MISSILE RANGE, NEW MEXICO  
Building Air Exchanges Per Hour: 0.47 (unsheltered double storied)  
Time: April 2, 2007 1305 hours MDT (user specified)

#### **CHEMICAL DATA:**

Chemical Name: CHLORINE                      Molecular Weight: 70.91 g/mol  
AEGL-1(60 min): 0.5 ppm   AEGL-2(60 min): 2 ppm   AEGL-3(60 min): 20 ppm  
IDLH: 10 ppm  
Ambient Boiling Point: -35.4° F  
Vapor Pressure at Ambient Temperature: greater than 1 atm  
Ambient Saturation Concentration: 1,000,000 ppm or 100.0%

#### **ATMOSPHERIC DATA:**

Wind: 5.23 meters/second from 218° true at 10 meters  
Ground Roughness: urban or forest   Cloud Cover: 0 tenths  
Air Temperature: 26.6° C                      Stability Class: C  
No Inversion Height                      Relative Humidity: 9%

#### **SOURCE STRENGTH:**

Direct Source: 200 gallons                      Source Height: 0  
Source State: Liquid  
Source Temperature: equal to ambient  
Release Duration: 1 minute  
Release Rate: 38.6 pounds/sec  
Total Amount Released: 2,318 pounds  
Note: This chemical may flash boil and/or result in two phase flow.

#### **THREAT ZONE:**

Model Run: Heavy Gas  
Red : 1.4 miles --- (20 ppm = AEGL-3(60 min))  
Orange: 3.1 miles --- (2 ppm = AEGL-2(60 min))  
Yellow: 5.0 miles --- (0.5 ppm = AEGL-1(60 min))

Simulated chemical threat description used by the ALOHA model.

Figure D-2. Simulated airborne chemical release threat description used by the ALOHA model.



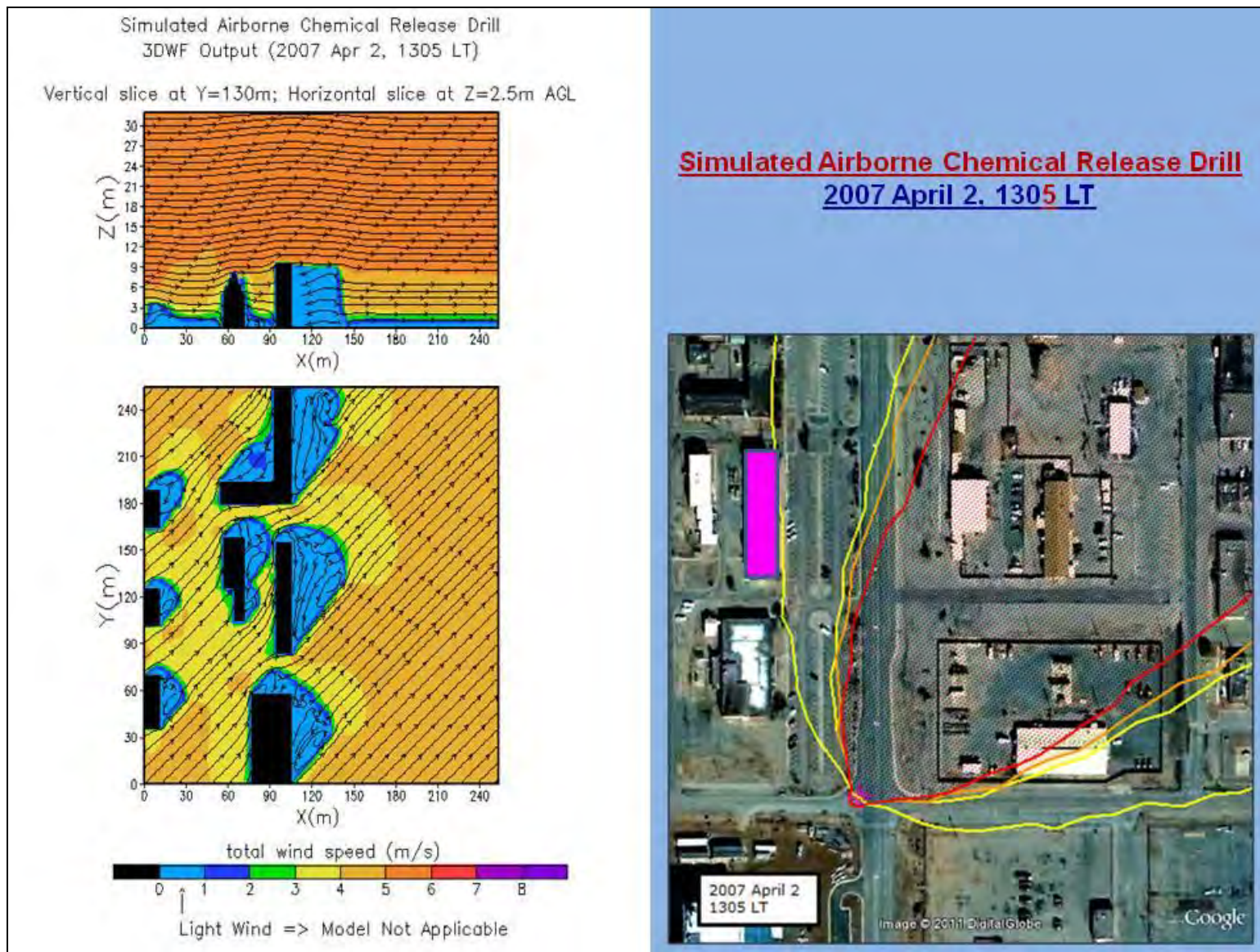


Figure D-3. Minute # 1 of a 16-minute sequence of both wind flow and simulated chemical release footprints (sequence continues through figure D-18).



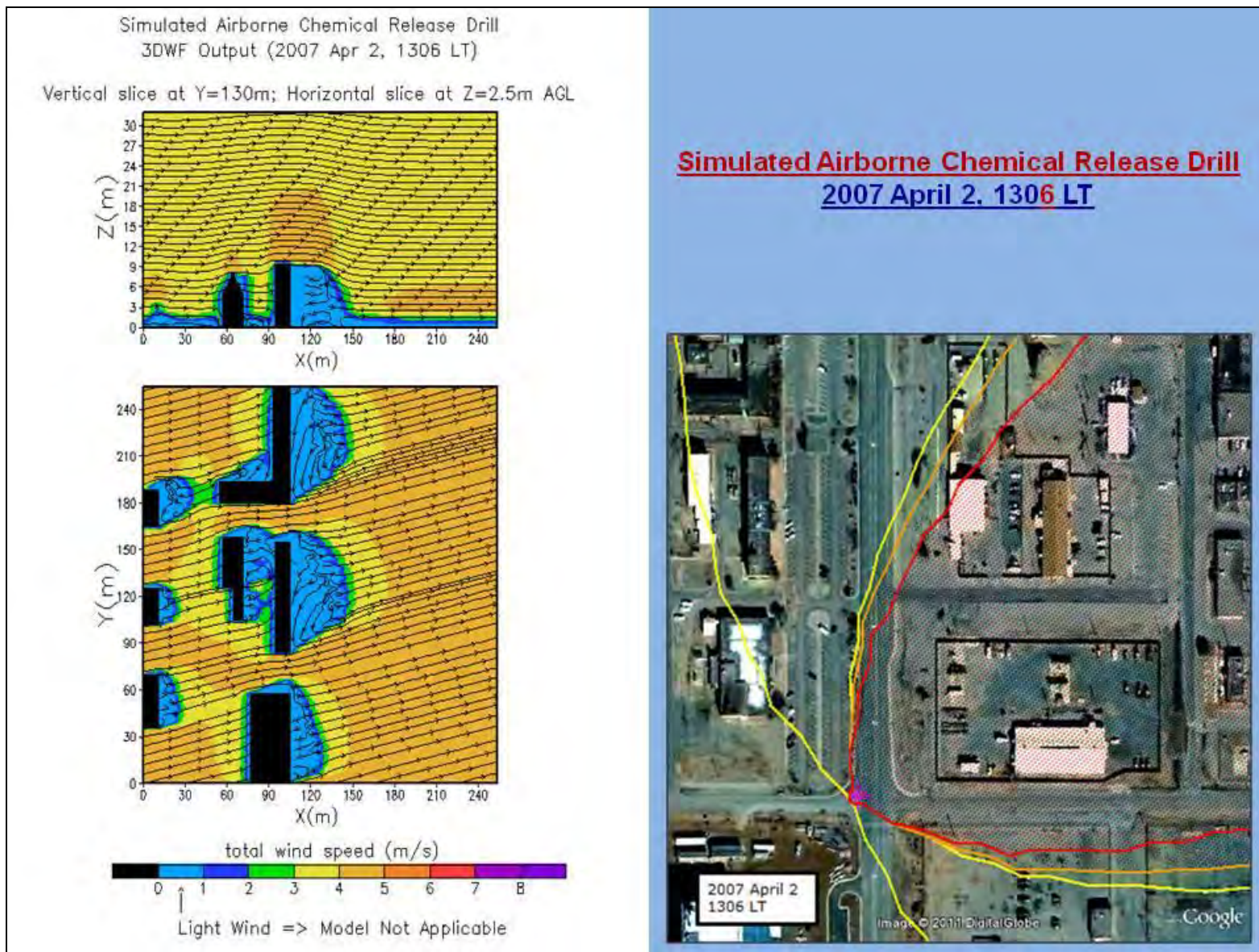


Figure D-4. Minute # 2 of a 16-min sequence of both wind flow and simulated chemical release footprints.



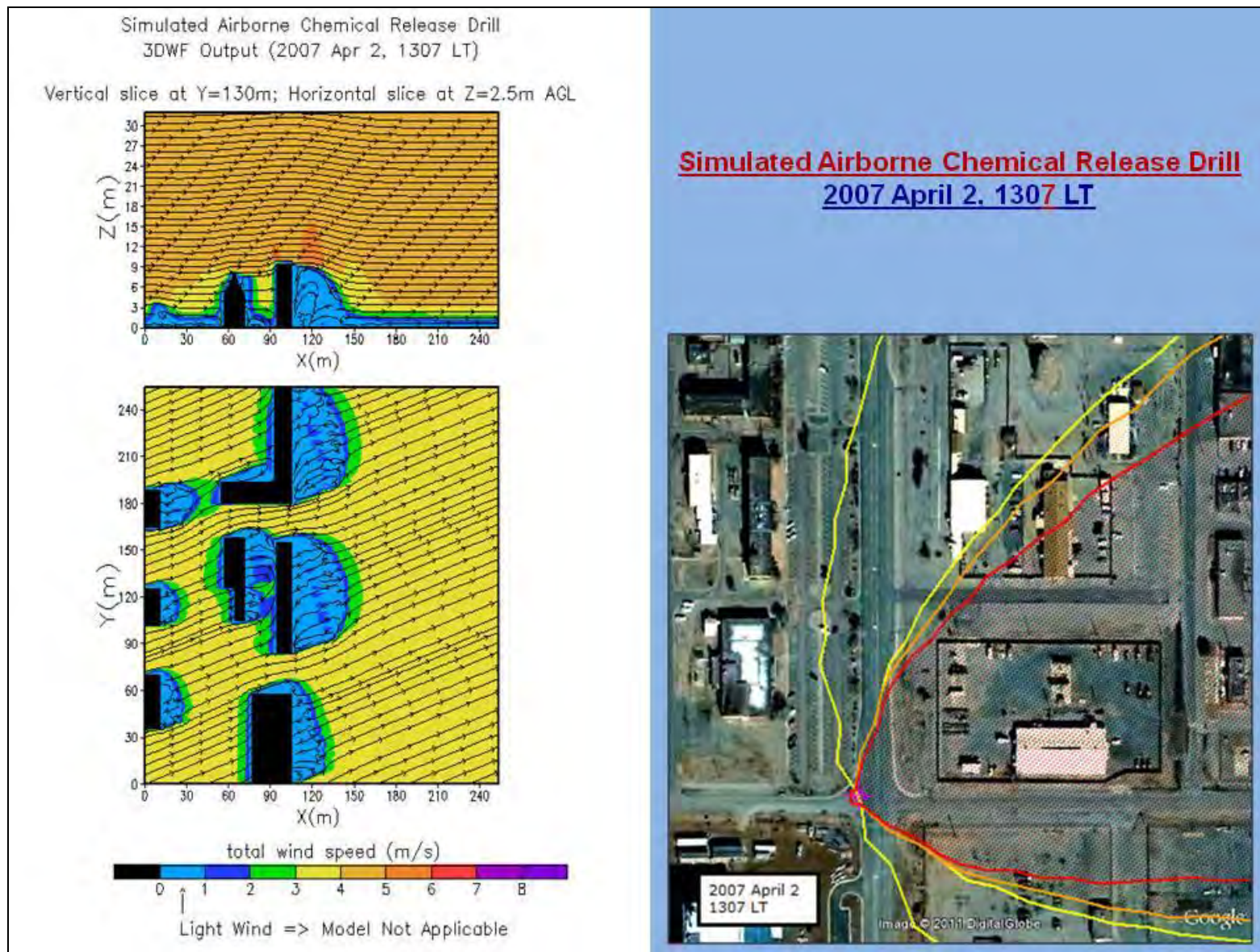


Figure D-5. Minute # 3 of a 16-min sequence of both wind flow and simulated chemical release footprints.



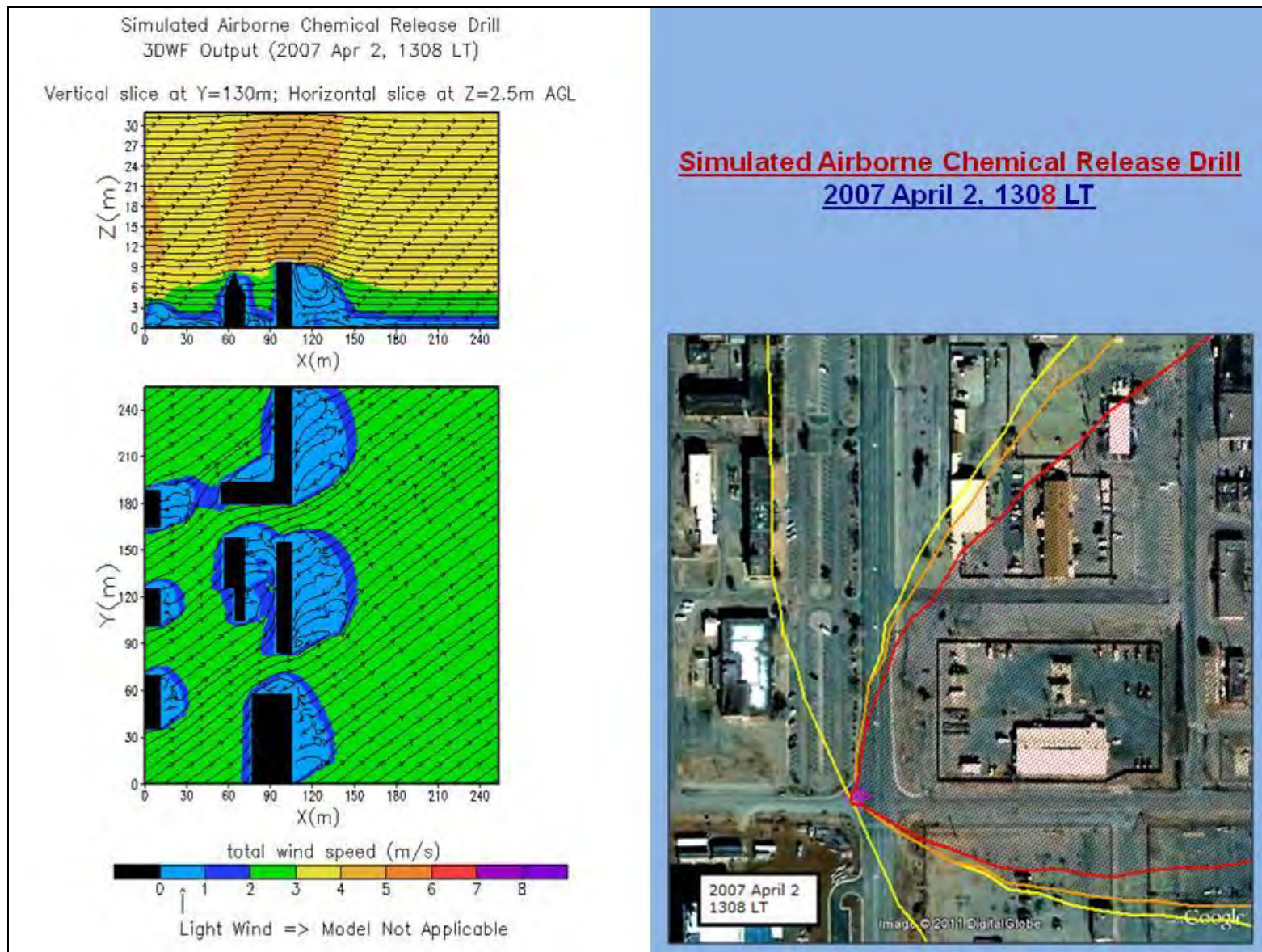


Figure D-6. Minute # 4 of a 16-min sequence of both wind flow and simulated chemical release footprints.



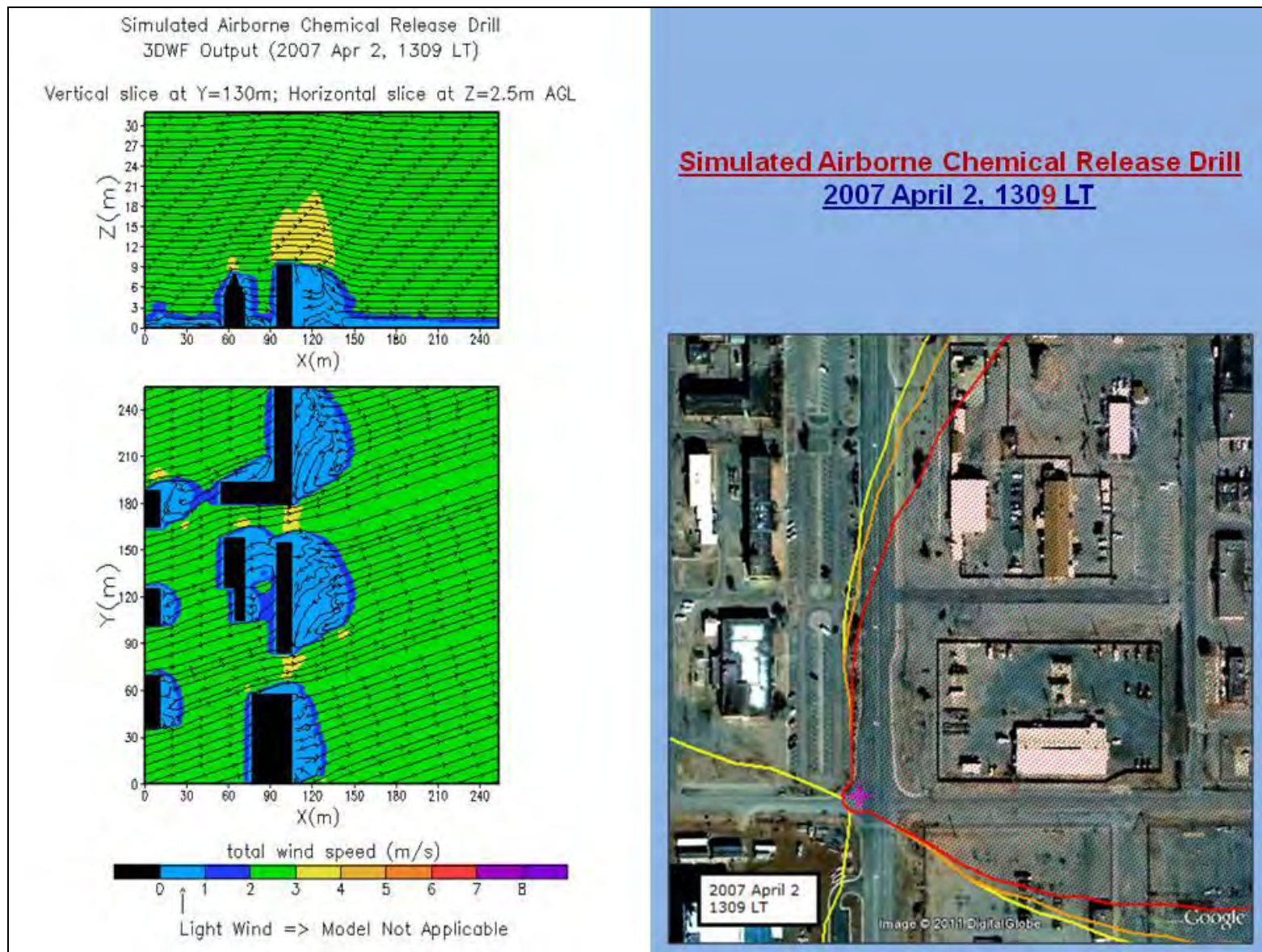


Figure D-7. Minute # 5 of a 16-min sequence of both wind flow and simulated chemical release footprints.



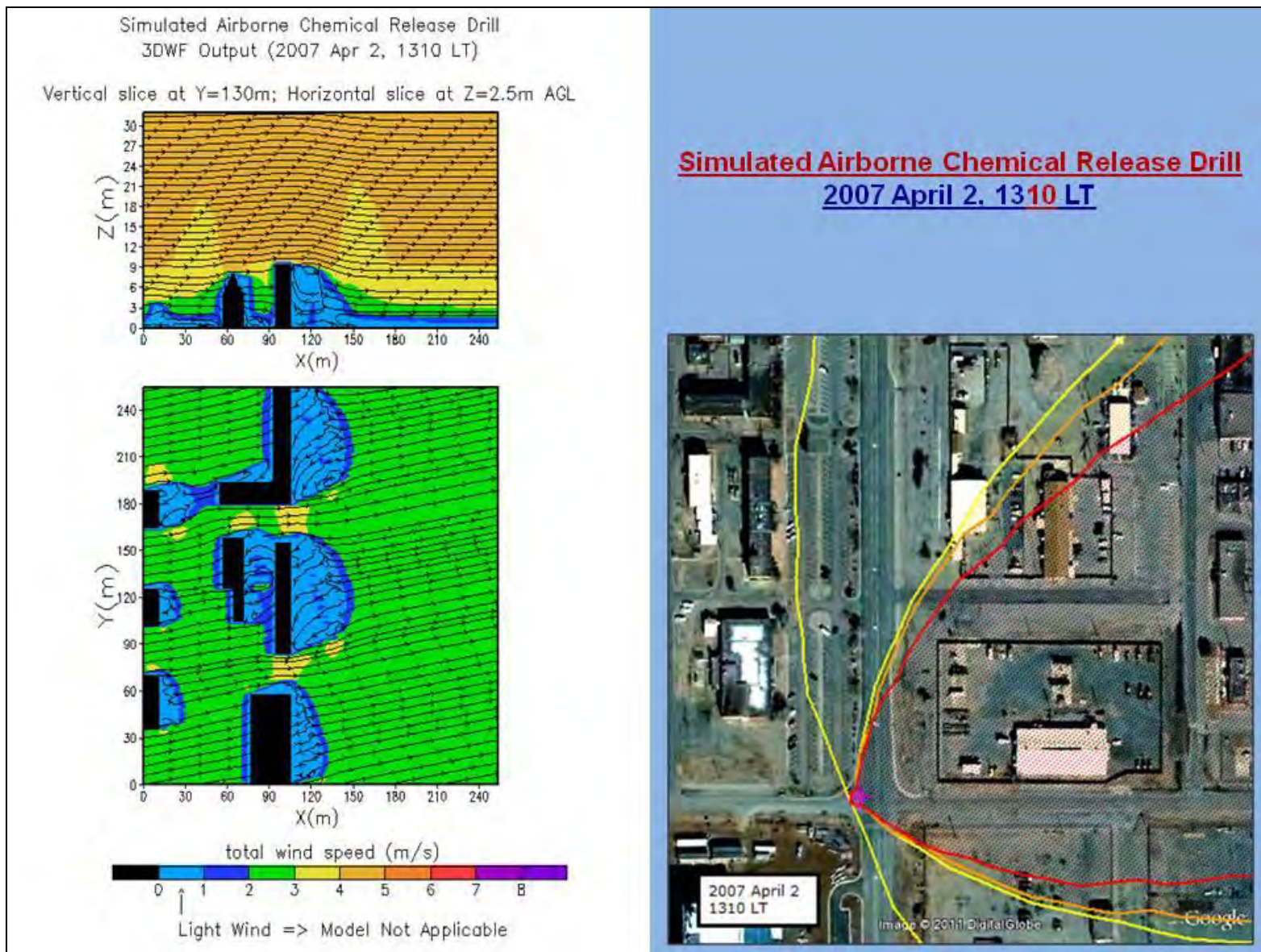


Figure D-8. Minute # 6 of a 16-min sequence of both wind flow and simulated chemical release footprints.



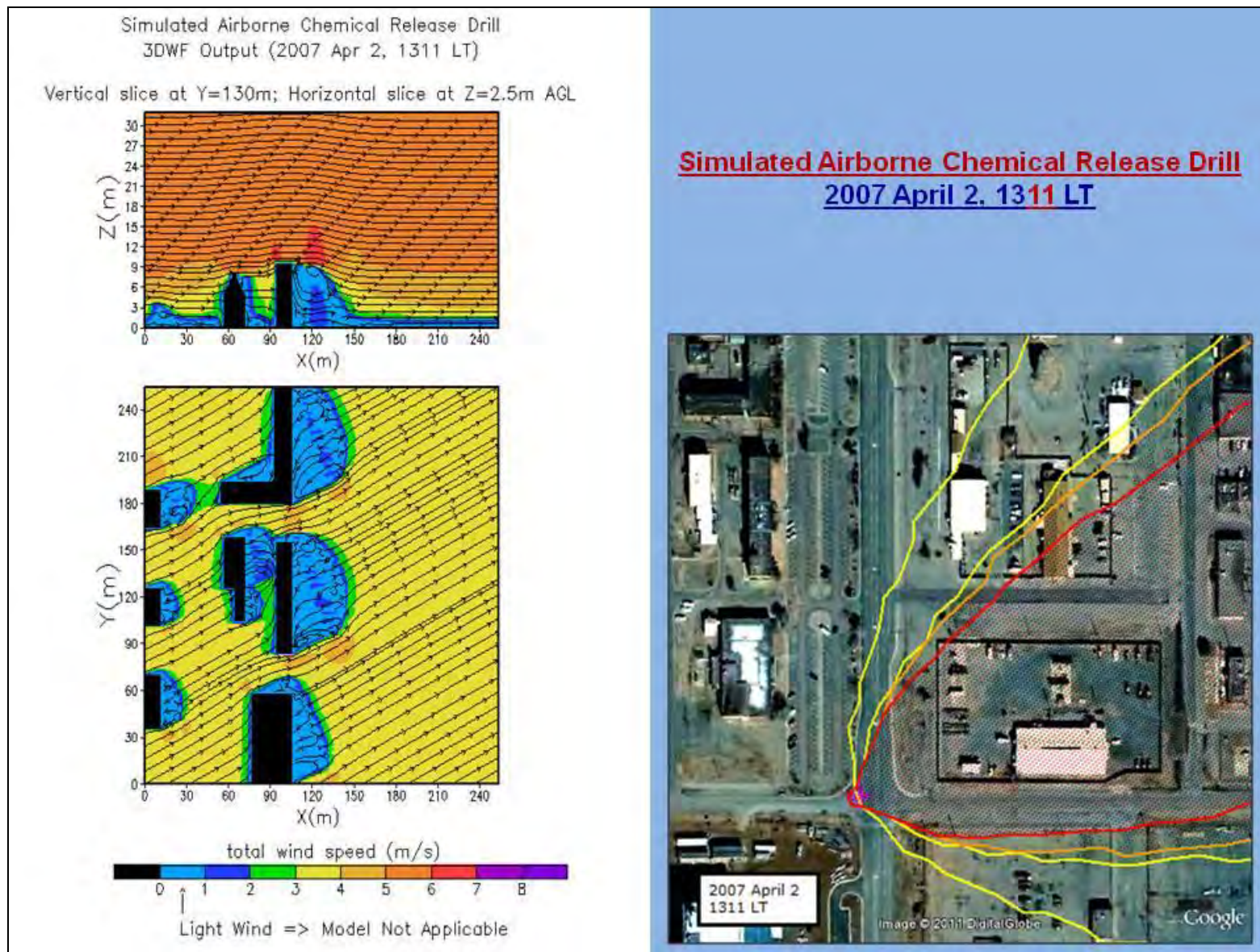


Figure D-9. Minute # 7 of a 16-min sequence of both wind flow and simulated chemical release footprints.



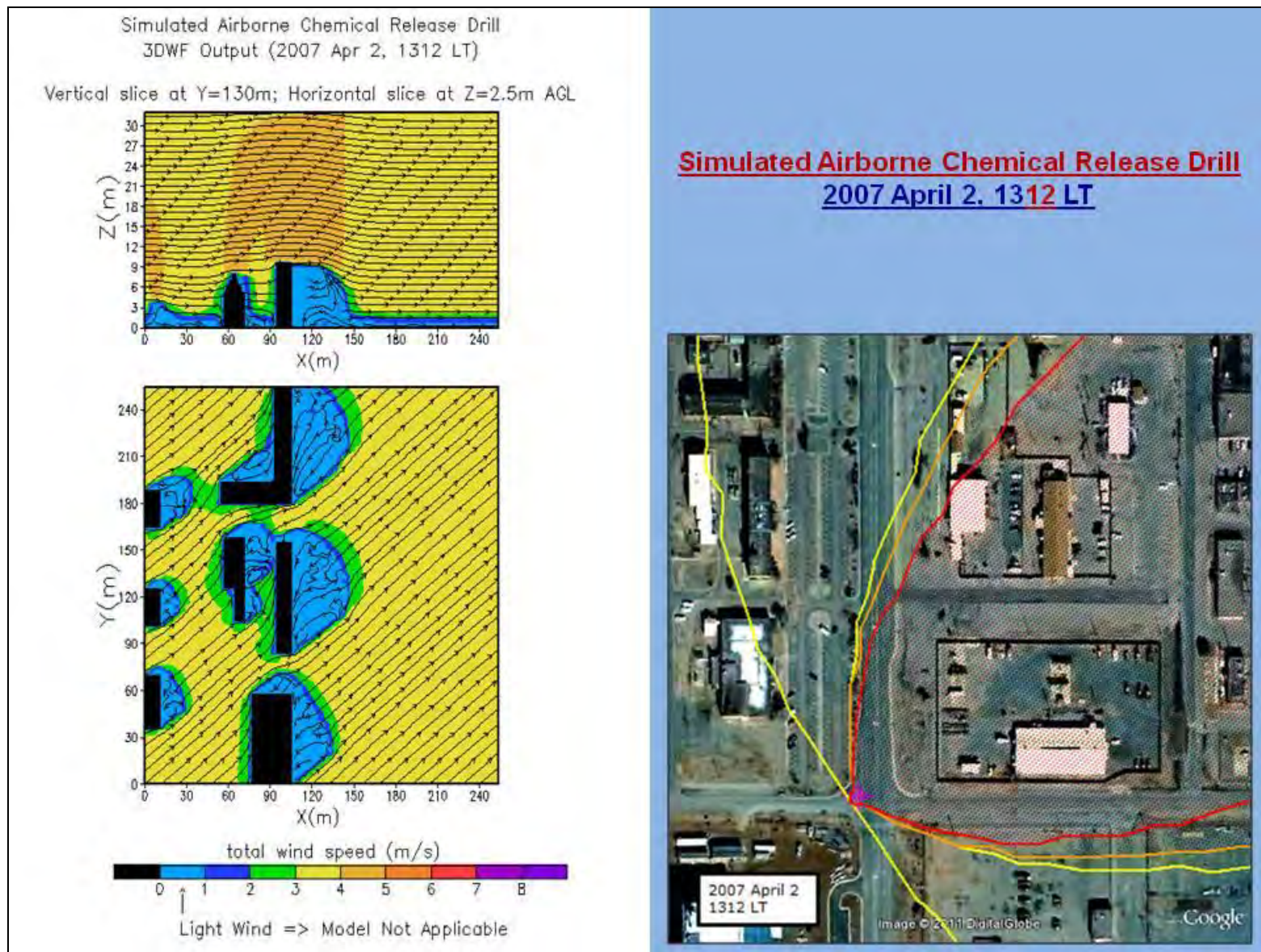


Figure D-10. Minute # 8 of a 16-min sequence of both wind flow and simulated chemical release footprints.



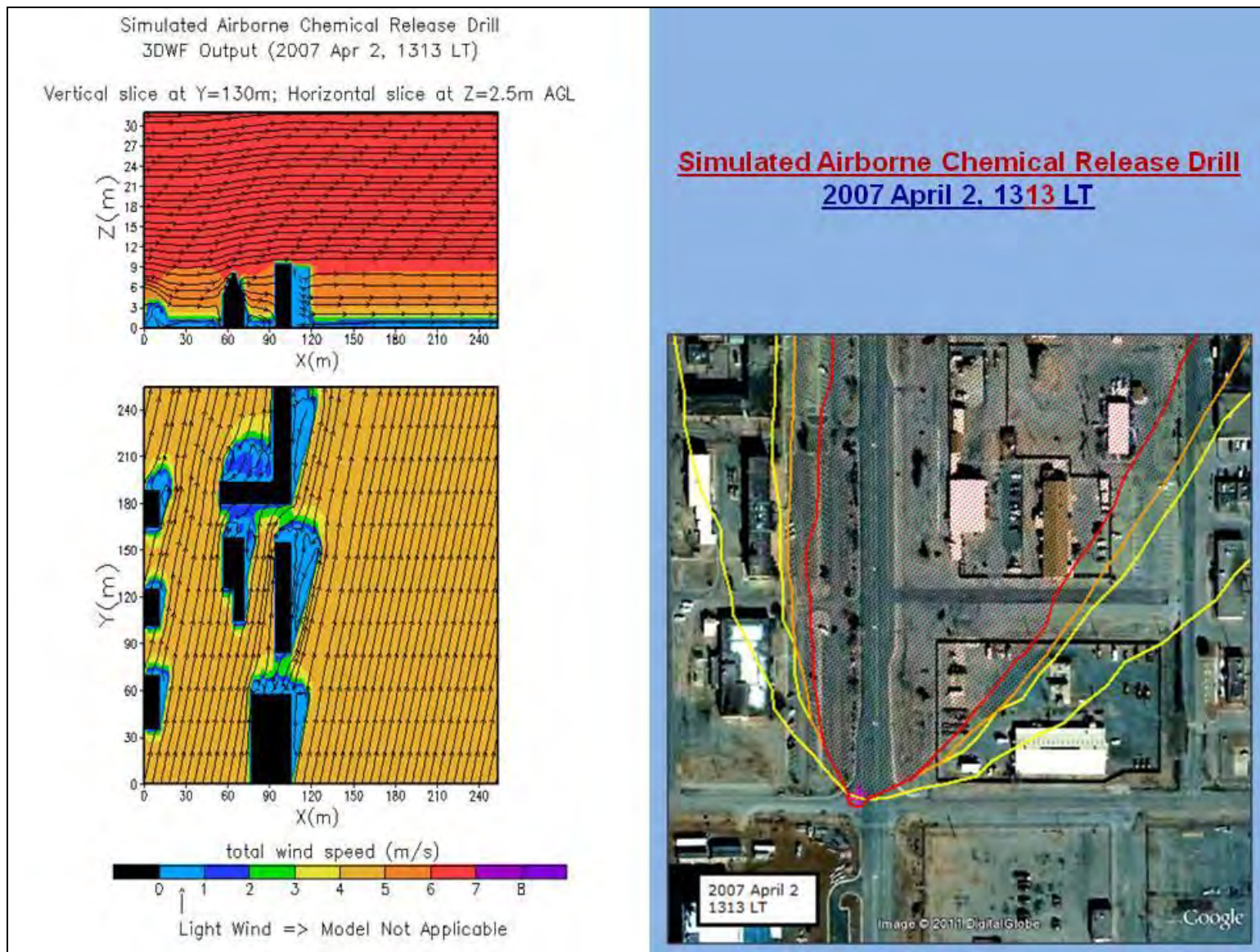


Figure D-11. Minute # 9 of a 16-min sequence of both wind flow and simulated chemical release footprints.

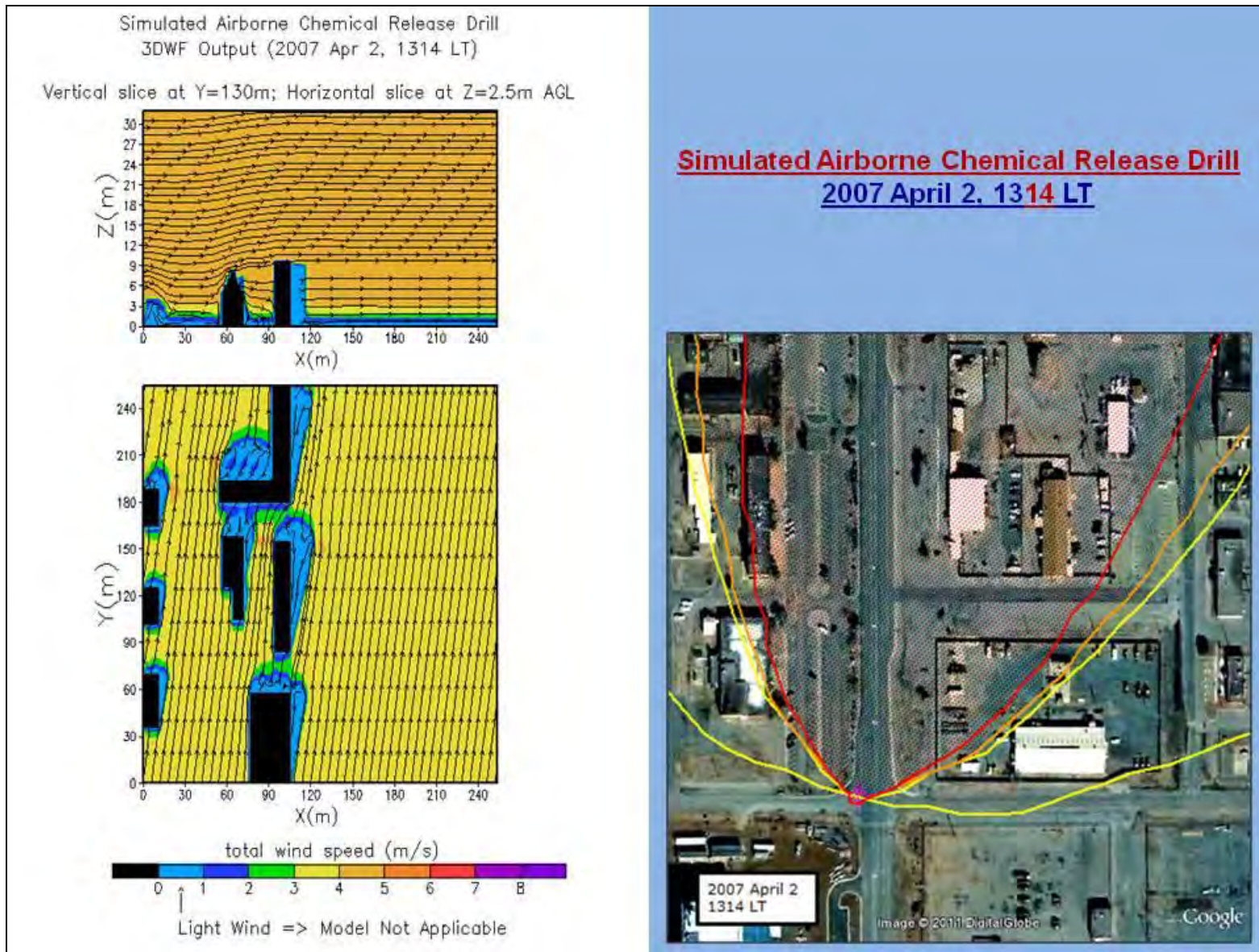


Figure D-12. Minute # 10 of a 16-min sequence of both wind flow and simulated chemical release footprints.



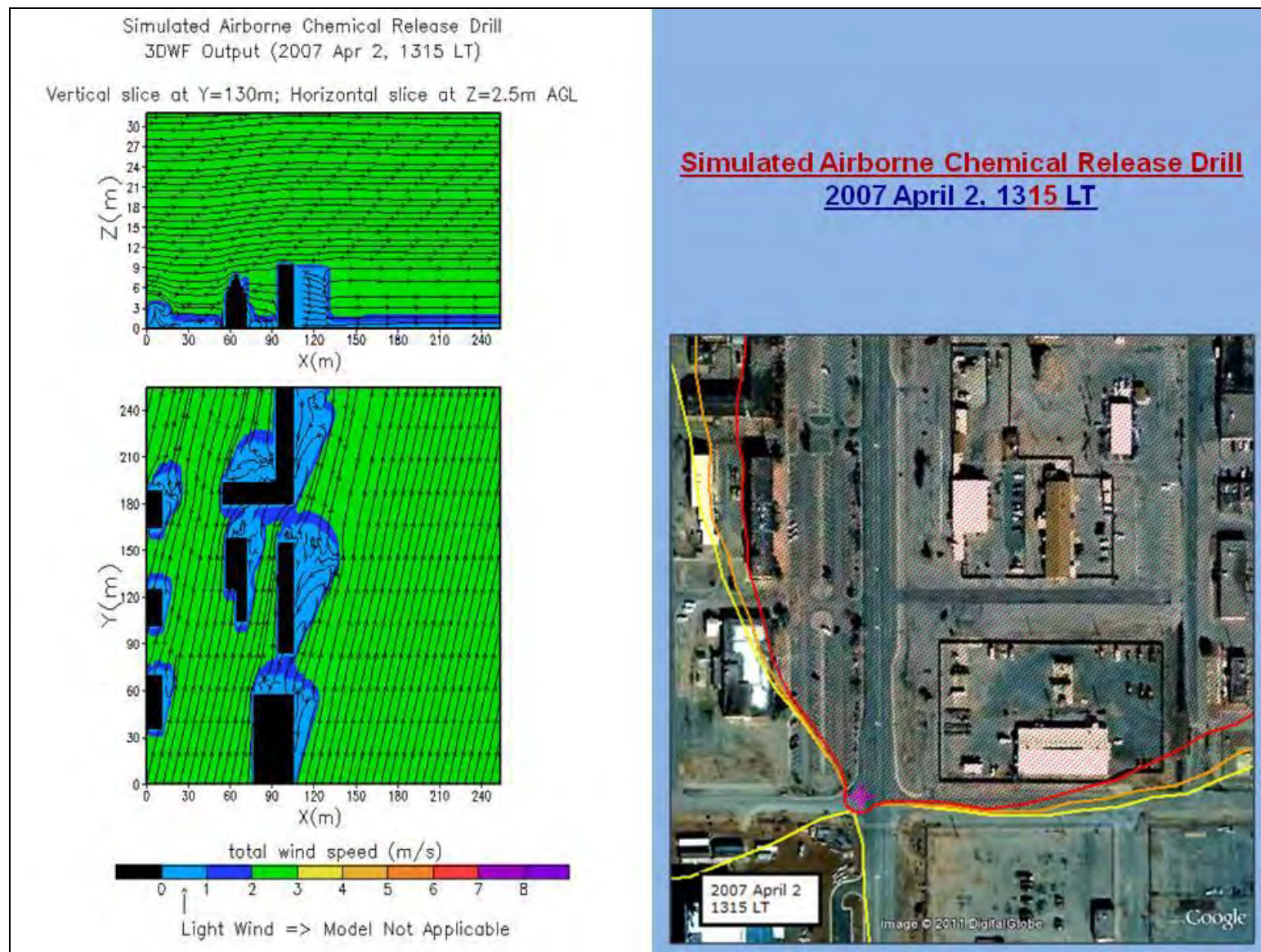


Figure D-13. Minute # 11 of a 16-min sequence of both wind flow and simulated chemical release footprints.

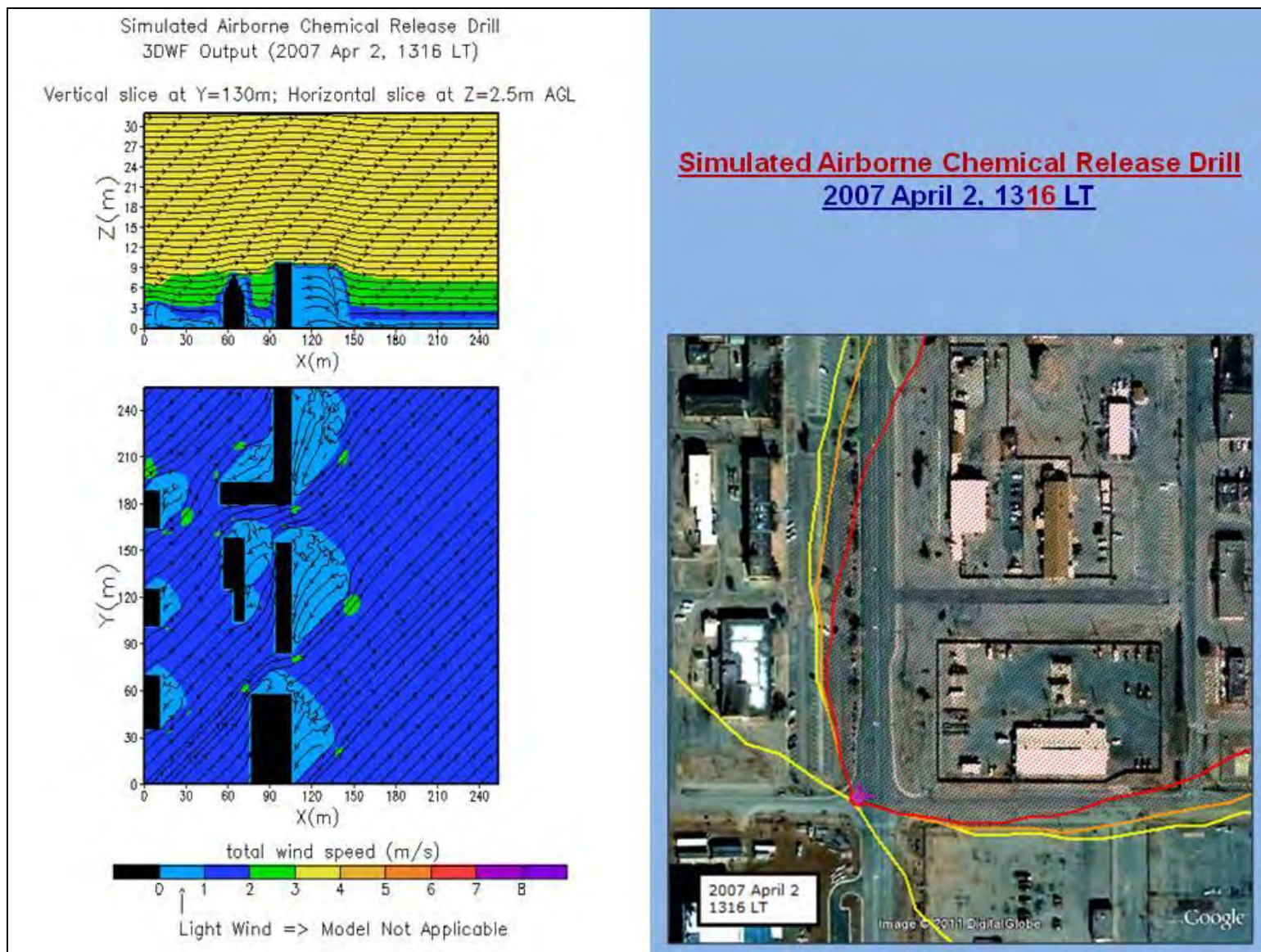


Figure D-14. Minute # 12 of a 16-min sequence of both wind flow and simulated chemical release footprints.



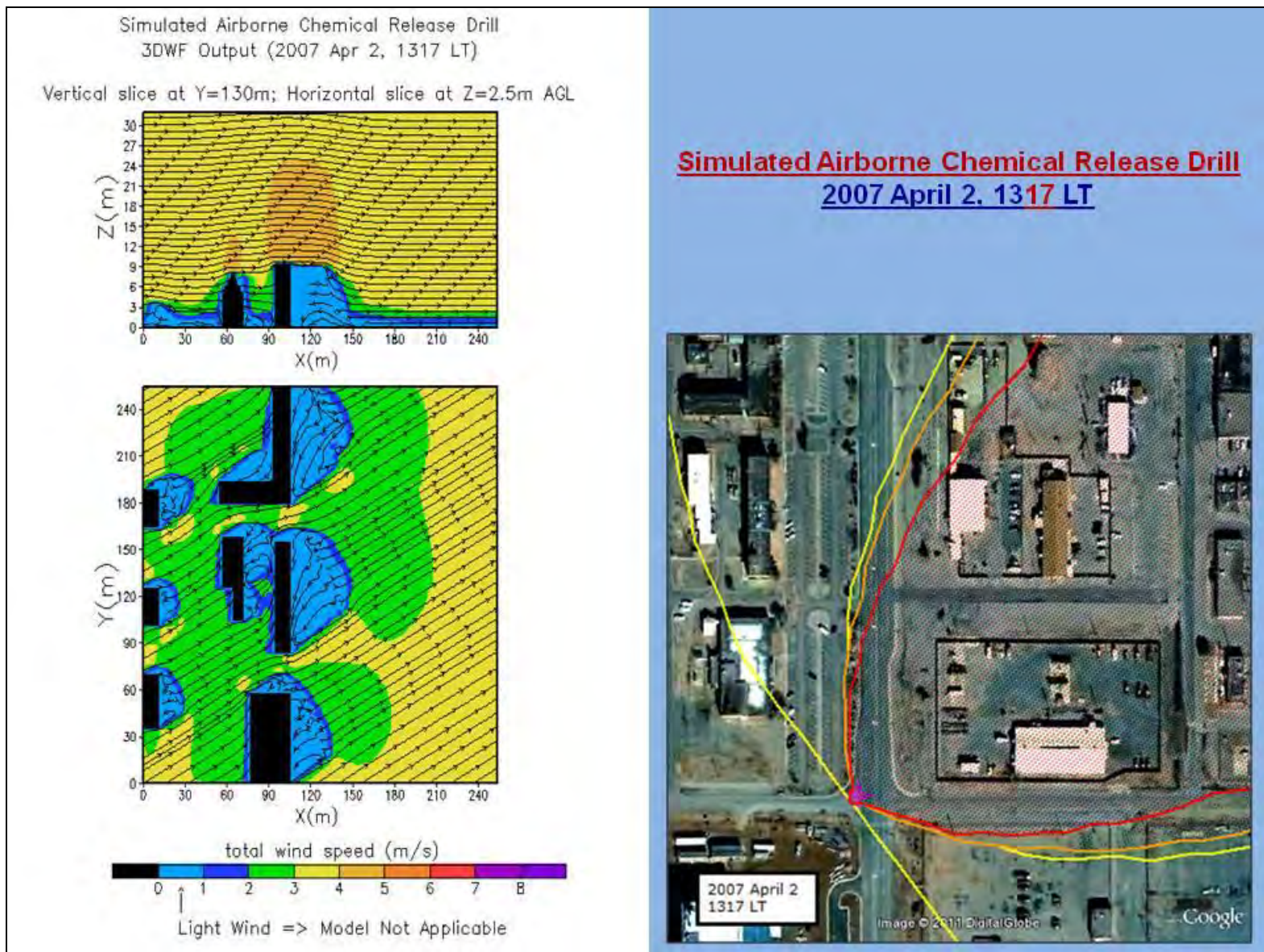


Figure D-15. Minute # 13 of a 16-minute sequence of both wind flow and simulated chemical release footprints.



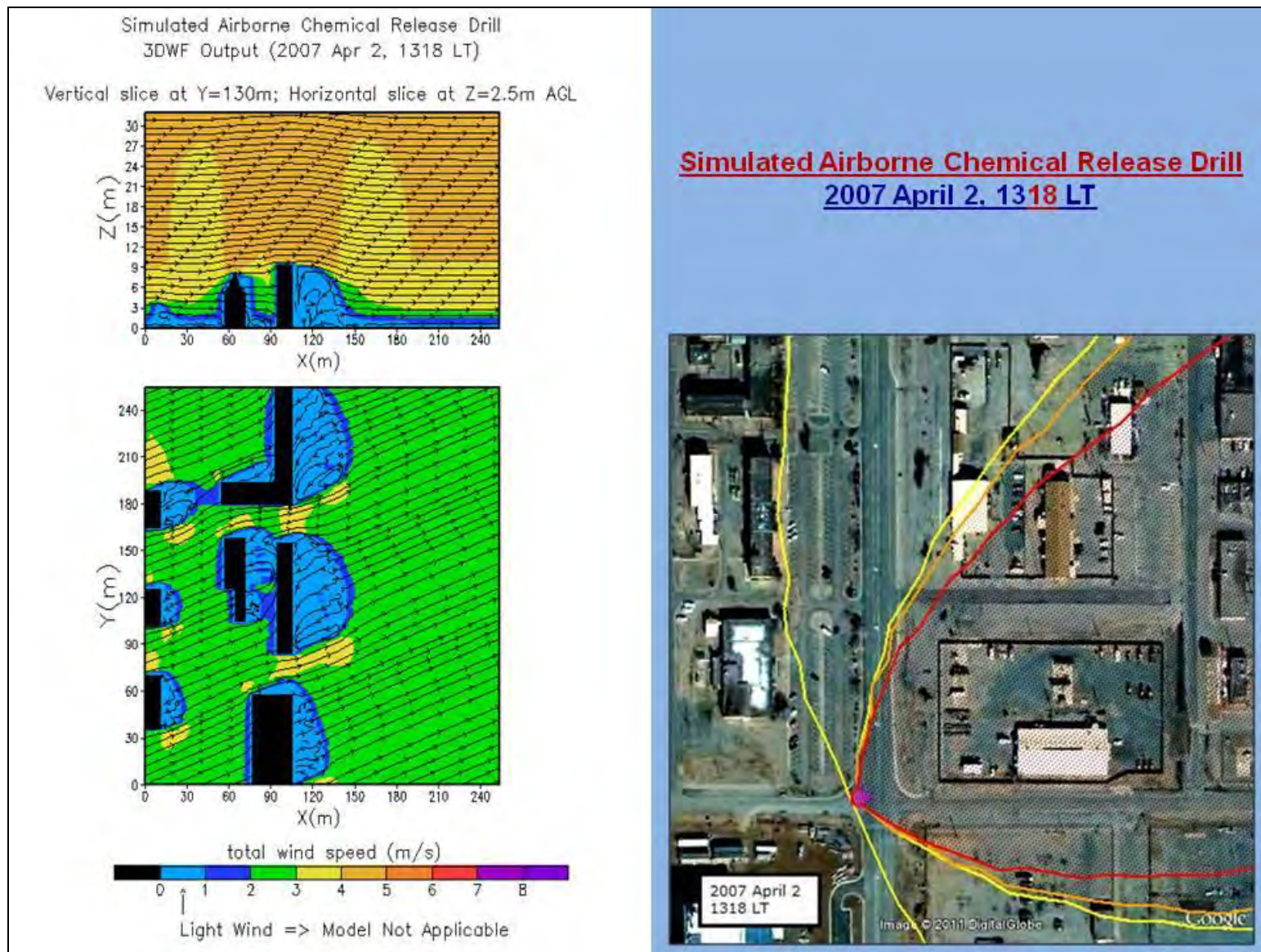


Figure D-16. Minute # 14 of a 16-minute sequence of both wind flow and simulated chemical release footprints.



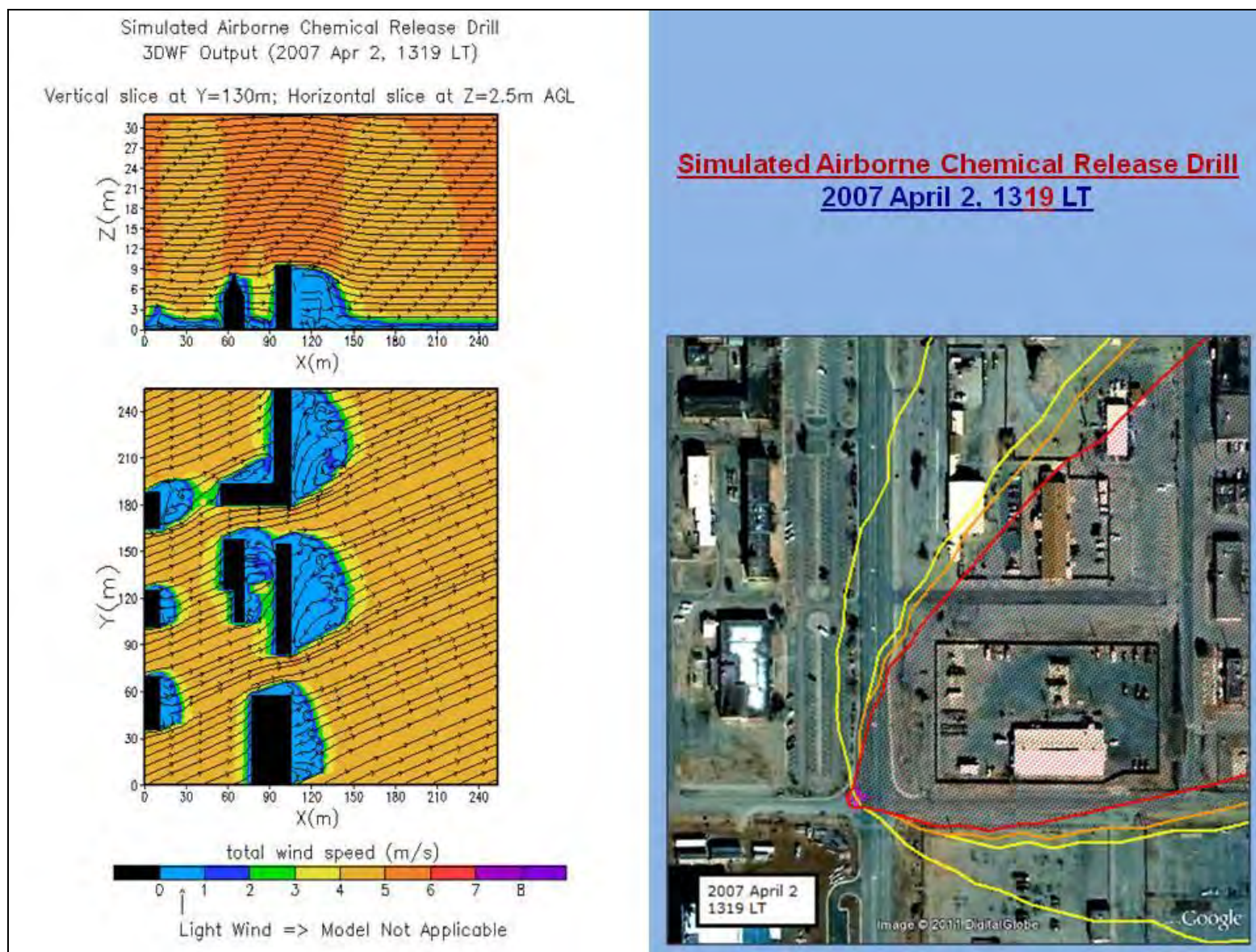


Figure D-17. Minute # 15 of a 16-min sequence of both wind flow and simulated chemical release footprints.



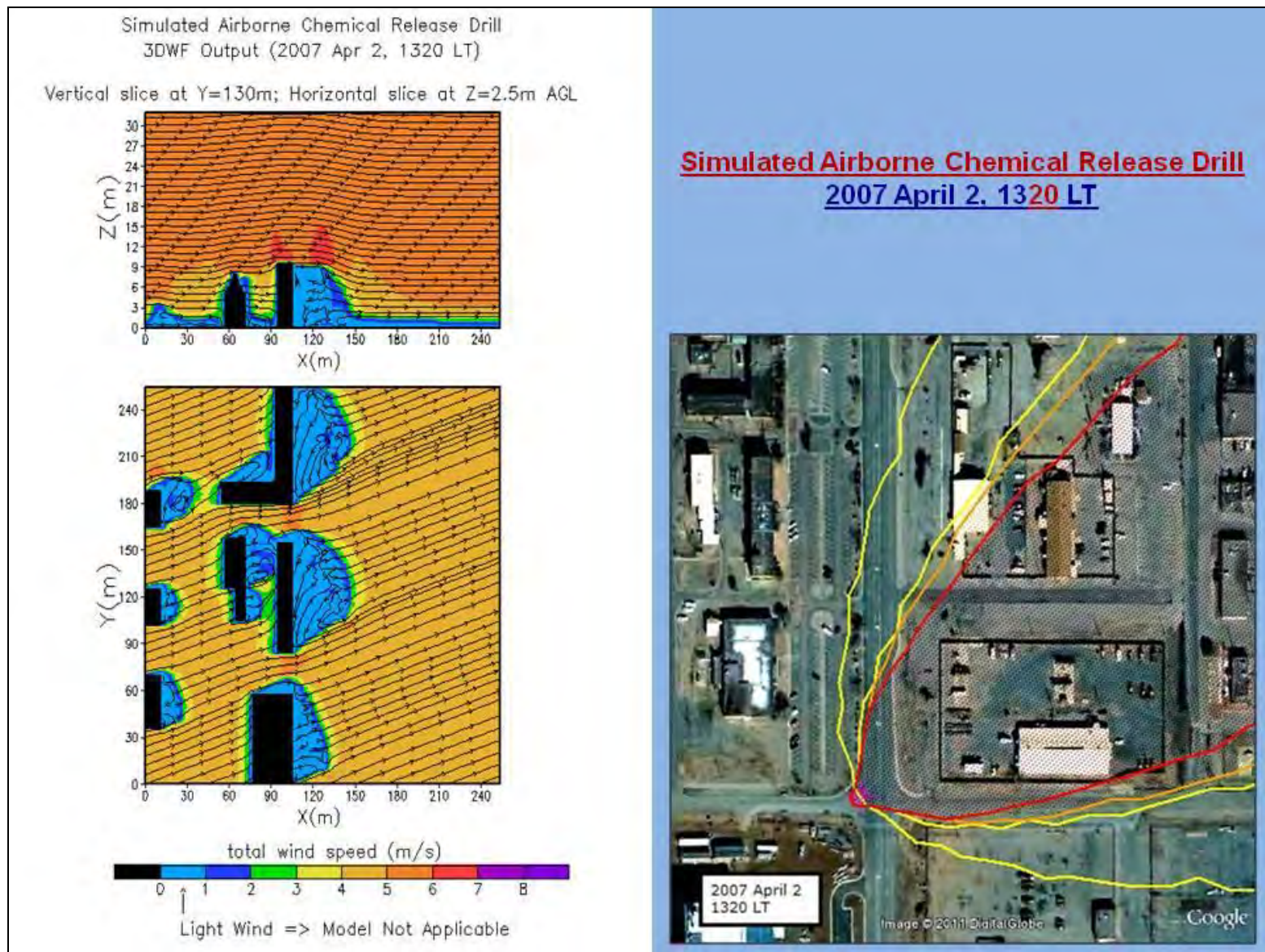


Figure D-18. Minute # 16 of a 16-min sequence of both wind flow and simulated chemical release footprints.



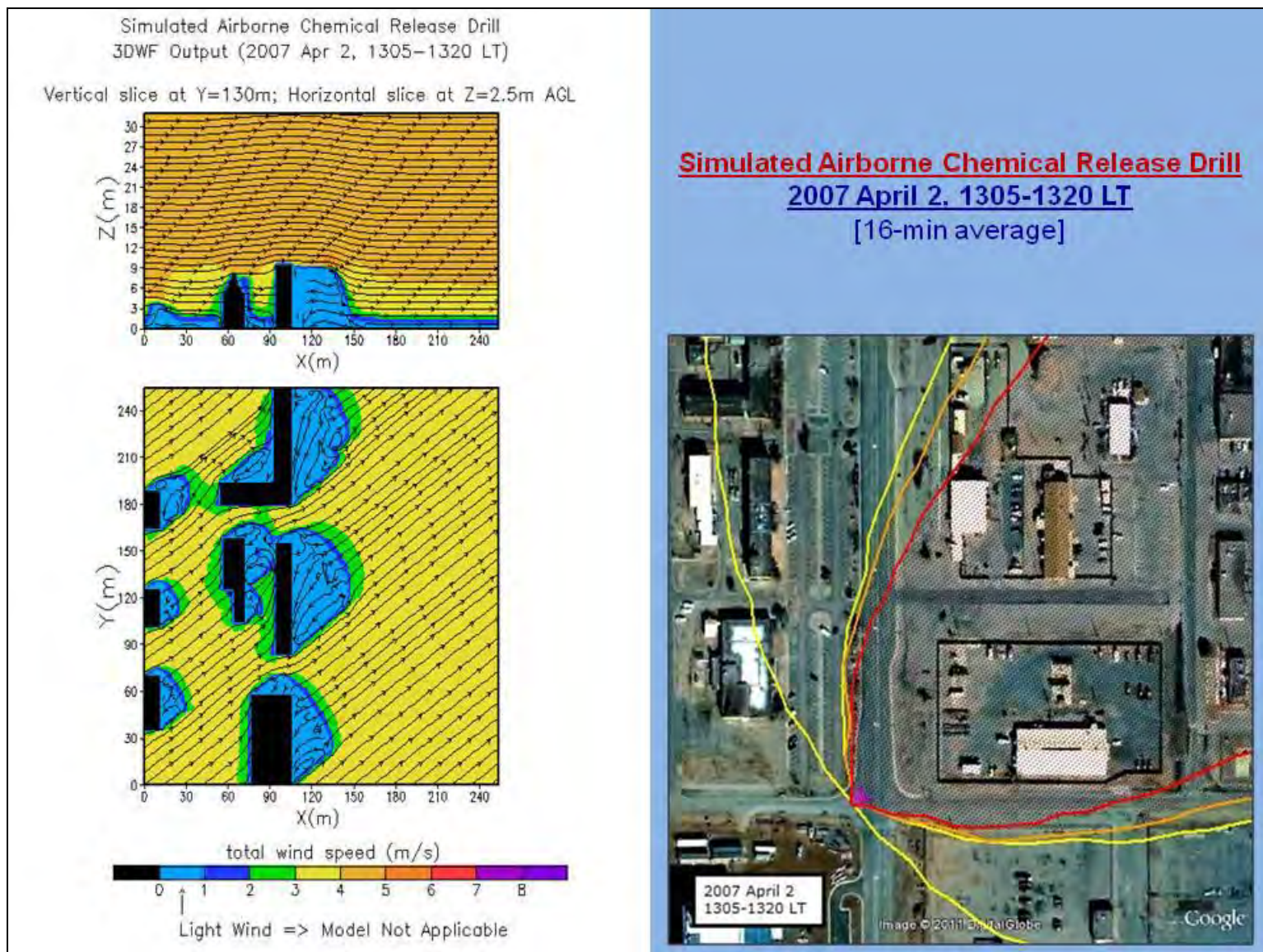


Figure D-19. A wind and plume representation based on 16-min averaged meteorological data input.



---

## List of Symbols, Abbreviations, and Acronyms

---

°C	degree Celsius (units)
24/7	24 hours per day/7 days a week
3DWF	3-Dimensional Wind Field
AEGL	Acute Exposure Guideline Level
AGL	Above Ground Level
AOI	area of interest
ArL	above roof level
ARL	U.S. Army Research Laboratory
deg	degrees (units)
EPA	Environmental Protection Agency
EUD	End User Display
gal	gallon
h	hour
HAZMAT	hazardous material
Hz	hertz (units)
IOC	Installation Operations Center
JD	Julian Date
lb	pound
LOC	level of concern
L-REAC™	Local-Rapid Evaluation of Atmospheric Conditions System
LT	local time (Mountain Time)
m	meters (units)
m/s	meters per second (units)
mb	millibars (units)

MDT	Mountain Daylight Time
MT	Mountain Time (equivalent to local time)
NE	northeast
NetRad	Net solar radiation
NOAA	National Oceanic and Atmospheric Administration
NWC	northwest canyon
PI	Principle Investigator
ppm	parts per million
Press	pressure
RAZ	Re-attachment Zone
RE	Re-attachment Zone-East
RH	Relative Humidity
SE	southeast
Sim ACR Drill	Simulated Airborne Chemical Release Drill
Sim Bomb Drill	Simulated Bomb Threat Drill
SIP	Shelter in Place
Solar Rad	Solar Radiation
SOP	Standard Operating Procedure
Std Dev	Standard Deviation
SW	southwest
T or Temp	temperature
Tvai	temperature measured by a Vaisala humicap
W/m <sup>2</sup>	watts per meter squared (units)
<i>W07US</i>	<i>WSMR 2007 Urban Study</i>
WD	Wind Direction
WS	Wind Speed
WSMR	White Sands Missile Range

<u>No. of Copies</u>	<u>Organization</u>
1 (PDF)	ADMNSTR DEFNS TECHL INFO CTR DTIC OCP 8725 JOHN J KINGMAN RD STE 0944 FT BELVOIR VA 22060-6218
3 HCs	US ARMY RSRCH LAB ATTN RDRL CIO MT TECHL PUB ATTN RDRL CIO LL TECHL LIB ATTN IMNE ALC HRR MAIL & RECORDS MGMT 2800 POWDER MILL ROAD ADELPHI MD 20783-11976
7 CDs 15 HCs	US ARMY RSRCH LAB G VAUCHER ATTN RDRL CIE D BLD 1622 WSMR NM 88002
Total:	26 (1 PDF, 7 CDs, 18 HCs)

INTENTIONALLY LEFT BLANK.